

TM-70-1011-6

# TECHNICAL MEMORANDUM

## IMPACT OF THE SPACE SHUTTLE ON SATELLITE PAYLOADS

Bellcomm



(NASA-CR-111111) IMPACT OF THE SPACE SHUTTLE ON SATELLITE PAYLOADS (CONTINUED)  
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# BELLCOMM, INC.

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### ABSTRACT

Areas of potential impact of the Space Shuttle on the unmanned satellite program have been examined. The satellite program contained in Option III of the 1969 report to the Space Task Group has been used as the reference mission model. The assumed Shuttle model has a 15 x 60 foot cargo bay and a round trip payload capability of either 25 or 50 thousand pounds to a 270 nm, 55° inclination orbit.

The Shuttle system (or Shuttle plus an upper stage) is found to be capable of delivering all the satellites in the mission model and recovering most of them (excluding planetary payloads). Low earth orbit satellites are amenable to direct Shuttle delivery or recovery, while higher altitude satellites require an upper stage. Agena and Centaur stages were considered for satellite delivery, while the Space Tug was considered for both delivery and recovery.

Two facility-class satellites, OAO and HEAO, were examined in some detail as candidates for the Shuttle mode. Design concepts are presented which illustrate potential advantages of the payload (weight and volume) delivery and recovery capability of the Shuttle. Possible implications of orbital servicing on satellite design are illustrated using the Nimbus satellite as an example.

To exploit Shuttle capability beyond strictly satellite applications, a concept for a manned experiment module to be carried in the Shuttle bay was investigated. The experiment program for this module is patterned after the NASA CV-990 airborne research program. Two versions of this concept are discussed, a small module to be flown piggyback on a satellite delivery/recovery mission, and a large module to be flown on an independent mission.

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One measure of the effect of the Shuttle on the satellite program is the cost savings which might be achieved. Under a specific set of assumptions regarding individual satellite mission cost savings, satellites which could be launched and/or recovered by the Shuttle and also show a cost savings have been grouped into a traffic model. This traffic model has been used to derive annual cost savings and number of Shuttle flights for Shuttles costing 3, 20, and 75 million dollars per round trip. (The effect of Shuttle development cost was not considered.) In a sample three year period, 1977-1979, average annual cost savings were calculated to be 140, 10, and 0 million dollars, respectively. The average number of Shuttle flights per year was 14, 4, and 0, respectively.

A final section on issues deals with two particular questions raised by this study: 1) a possible role for an interim, 75 million dollar per mission Shuttle, and 2) the merits of making further perturbations on the traffic model before in depth studies are carried out to achieve better estimates for savings which might be realized through satellite redesign and reprogramming for the Shuttle mode.

The format for this report consists of charts and supporting text. The charts, with minor modifications, were contained in a vu-graph presentation at NASA Headquarters on June 30, 1970.

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**IMPACT OF THE SPACE SHUTTLE  
ON SATELLITE PAYLOADS**

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## IMPACT OF THE SPACE SHUTTLE ON SATELLITE PAYLOADS

### INTRODUCTION

The objective of this study is to make a preliminary assessment of how the availability of the Space Shuttle might affect the operation of satellite programs of the future. Operational modes to be explored include Shuttle capabilities for satellite launch, revisit, and recovery, as well as the option to place man at the satellite site in earth orbit. Implications of the various operational modes for satellite design concepts will be discussed in general terms using specific, known satellites as examples.

One of the obvious questions which this paper addresses in a final section concerns the traffic model, i.e., how many Shuttle flights per year would be devoted to satellite missions. To provide an answer to this type of question, two elements are required: a model for the payload market and a set of criteria which divides satellite missions into conventional vs. Shuttle modes of operation. The payload market is taken to be the 1970-1981 satellite mission model derived from Option III of the NASA report to the Space Task Group (STG), as compiled by Battelle Memorial Institute. This model is documented on the following two charts.

The two criteria for applicability of the Shuttle mode are Shuttle performance and cost. Shuttle performance parameters are derived from the Shuttle work statement and various contractor reports. The cost tradeoff employed here is vastly simplified, using satellite and launch vehicle cost data from the NASA Planning Steering Group documentation and assumed Shuttle round trip costs of 3, 20, and 75 million dollars. These costs approximately cover the range between completely reusable and interim, partially reusable concepts.

Because the results of this study are more applicable to classes of satellites rather than to specific spacecraft or missions, it is felt that nothing is lost if the entire 1970-1981 satellite mission model is used, even though the Shuttle is not expected to be available until the latter portion of that time period. This has the advantage of bringing into the discussion examples of satellites which are generally well known, making the results more understandable. This seems justified since there appears to be no substantial change in the character of satellite spacecraft and missions over the time period of the mission model which would affect the study results.



PROJECT                      LAUNCH VEHICLE      70   71   72   73   74   75   76   77   78   79   80   81   TOT. SATS.

NASA PLANETARY AND INTERPLANETARY

SPACE PHYSICS													
SOLAR WEATHER	TAT/DELTA/KICK				1								1
HELIOS, PIONEER	A/C, T-3D/CENTAUR		1		1			1	1				4
BIOSCIENCE													
PIONEER	TAT/DELTA/KICK		1		1		1		1				3
PLANETARY													
MARS	A/C, T-3D/CENTAUR	2		2		1					1		8
VENUS	TAT/DELTA/KICK			2	1			1		1			6
JUPITER, OUTER PLANETS	A/C, T-3D/CENTAUR/KICK		1	1		2	1	2					7
ASTEROID, COMET,													
MERCURY	A/C, T-3C		1			1						1	3

NON-NASA EARTH ORBITAL

COMMUNICATIONS													
INTELSAT, DOMESTIC													
AND FOREIGN	TAT/DELTA/KICK, A/C	4	3	4	5	6	4	4	5	7	4	4	50
EARTH OBSERVATIONS													
ESSA	TAT/AGENA, TAT/DELTA/ KICK	2	3	3	4	1	3	3	2	4	1	3	32
INTERNATIONAL PROGRAMS	SCOUT, DELTA, CENTAUR	2	3	2	2	2	3	3	2	2	2	4	30
DOD PROGRAMS	SCOUT, DELTA, CENTAUR	6	3	5	7	4	4	4	4	4	4	4	53

---

TOTAL NO. OF SATELLITES (EXCLUDING ATM)      20   24   23   32   33   37   31   33   22   33   17   23   328

## MISSION MODEL CHARACTERIZATION

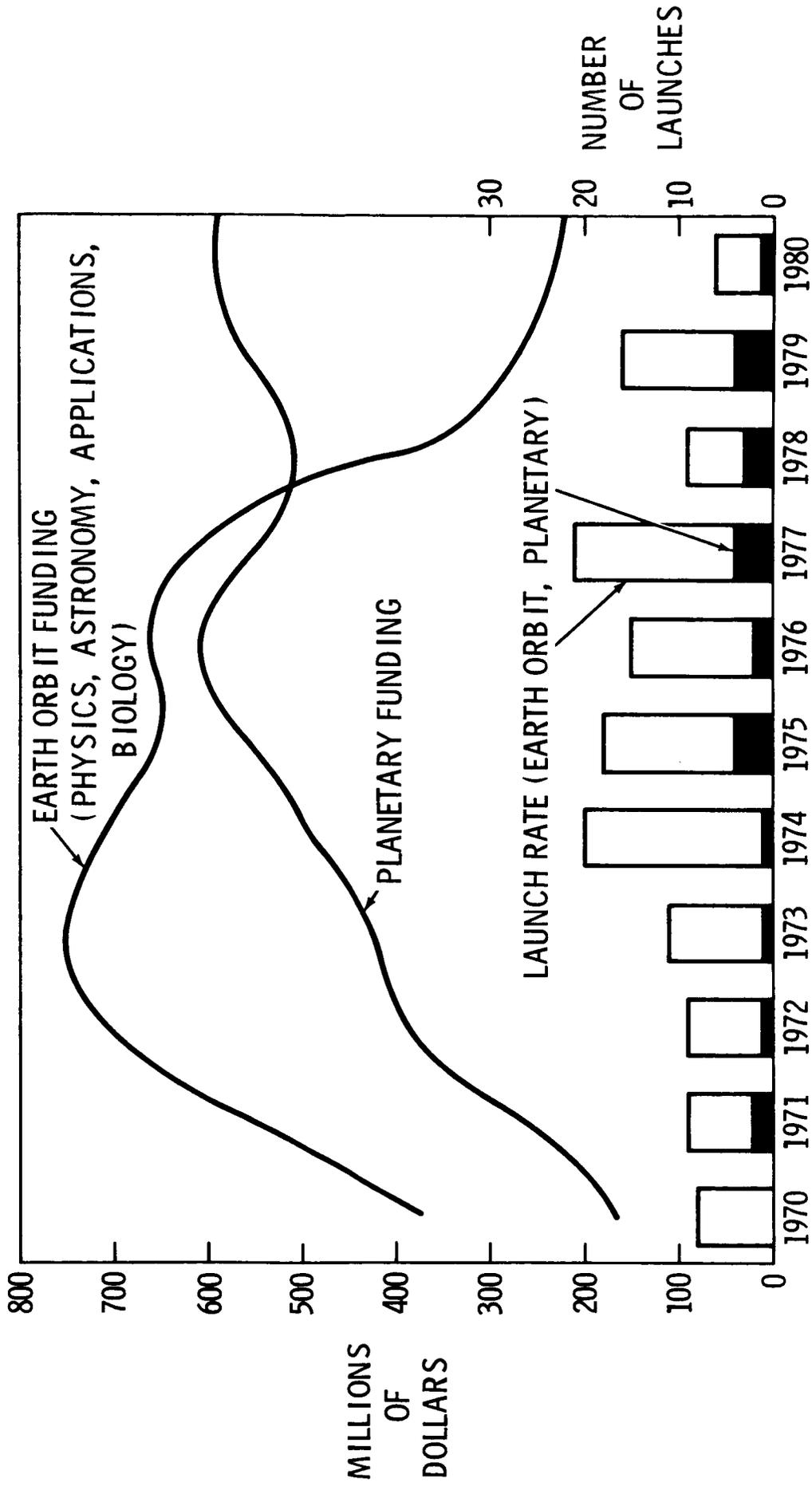
Before proceeding with the analysis, it is worthwhile characterizing the satellite mission model which is the basis for examining possible modes of Shuttle interaction.

The following chart exposes two important features of the OSSA satellite program: (1) from a dollar standpoint, the planetary program should be considered comparable to the earth orbital program, and (2) the investment in earth orbital satellites decreases noticeably after the introduction of the space station and Shuttle (1977). The assumption in the planning process which led to this program was that much of the earth orbital experiment program would be transferred from satellites to the space station after 1977. This suggests that the satellite program is not a true representation of the planned payload market in the Shuttle time period. In view of this, plus the real uncertainty over which elements of this long range plan will actually materialize, it was concluded that the objectives of this study would benefit most from a consideration of the broadest range of possible missions. For this reason the entire 1970-1981 satellite mission model will be used, although attention will at times focus on those years in which the plan indicates availability of the Shuttle.

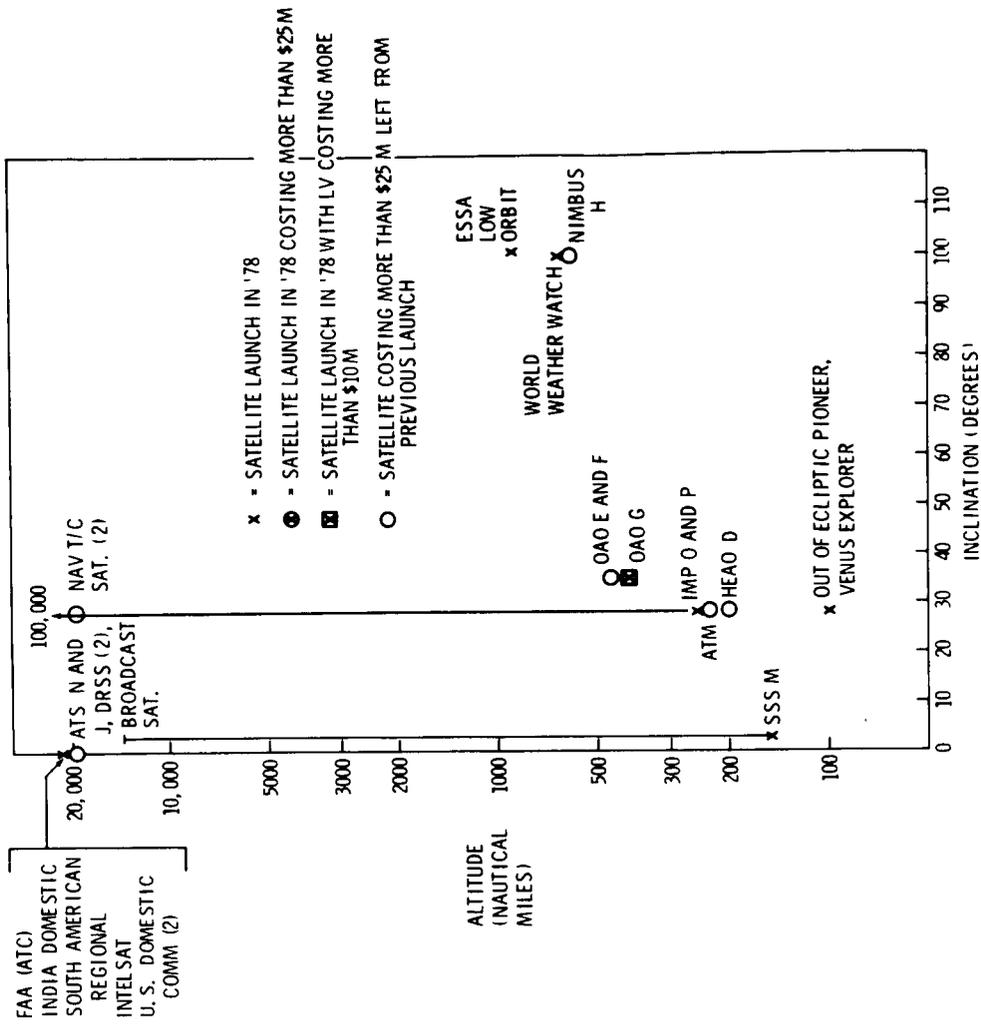
The next chart characterizes the earth orbit satellite population in two years, 1977 and 1978, in terms of orbit and cost (international and DOD programs were excluded because of insufficient information). The chart reveals that most satellites involving most of the total costs are in three orbit categories: 30° inclination, 200-500 nm; sun-synchronous orbits of 300-1000 nm; and equatorial, geosynchronous orbits. The decrease in the number of new launches of expensive satellites in 1978 compared to 1977 illustrates the earlier generalization regarding transfer of payloads to the space station.

# MISSION MODEL CHARACTERIZATION

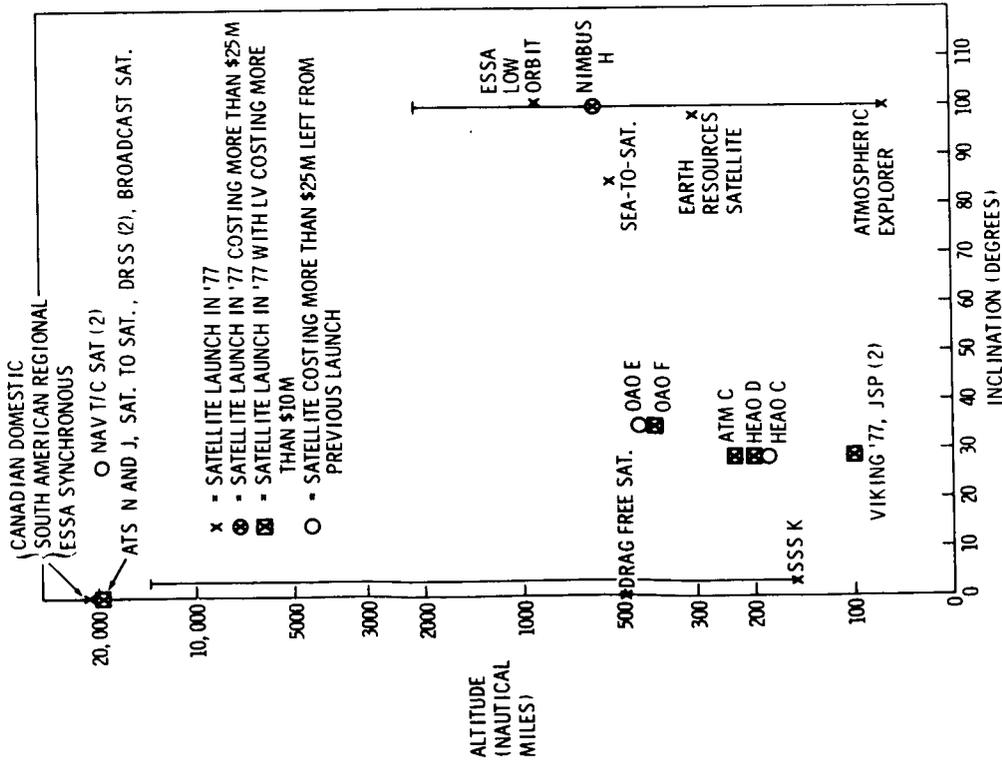
## OSSA FUNDING AND LAUNCH RATES



SATELLITE POPULATION - 1978



SATELLITE POPULATION - 1977



### SPACE SHUTTLE PERFORMANCE

The feasibility of employing a reusable Space Shuttle for launching, visiting, and recovering satellites is discussed in this section. Performance characteristics are assumed for a typical Shuttle and the resulting satellite delivery and recovery capabilities are shown. Examples are given of missions which a Shuttle can perform directly or with the aid of an upper stage for the satellite. Upper stages which are considered in this study include Agena, Centaur, and a 50K pound gross weight Space Tug.

## SPACE SHUTTLE MODEL

Two of the characteristics which are called for in the Space Shuttle work statement are that the Shuttle orbiter have a useful orbit staytime of at least seven days and that it have an unpressurized cargo bay 60 feet long and 15 feet in diameter. For purposes of this study, we also assume that EVA is possible in the vicinity of the orbiter and that there are attach points for payloads and deployment mechanisms.

The performance characteristics assumed for the Space Shuttle are shown on the accompanying chart. These represent typical Shuttle performance, based on the major contractor studies. Note that the nominal round-trip payload between the earth and a space station orbit at 55°/270 nm could be either 25,000 or 50,000 pounds. (These two concepts will be referred to in this report as the "25K Shuttle" and the "50K Shuttle," respectively.) In order to keep the gross weight and burnout weight fixed, it is assumed that the higher payload is the result of a correspondingly lighter orbiter.

Subsequent charts will show how the payload capacity of these two conceptual vehicles varies with different destination orbits.

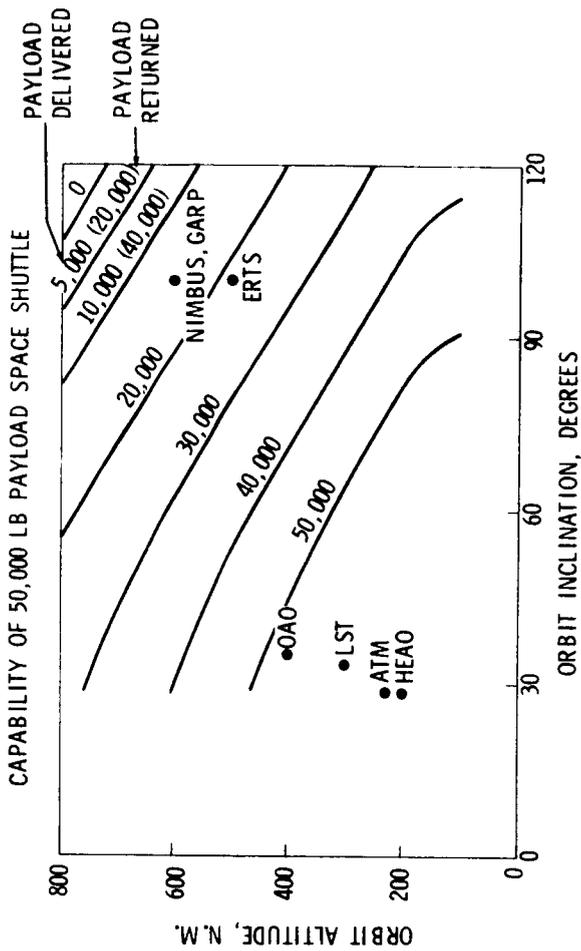
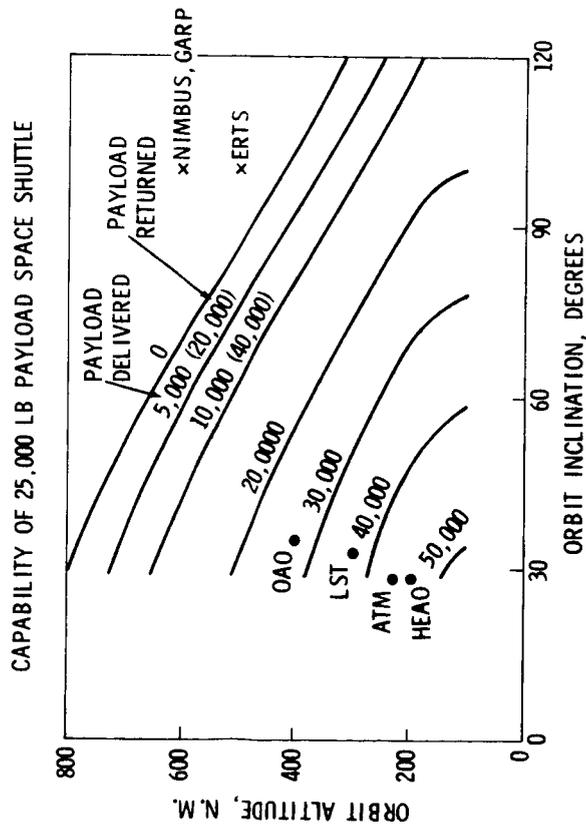
SPACE SHUTTLE MODEL

	<u>COMBINED</u>	<u>BOOSTER</u>	<u>ORBITER</u>
GROSS WEIGHT (LBS)	3,500,000	2,789,000	711,000 (WITH P/L)
PROPELLANT (LBS)	2,780,000	2,287,000	493,000
BURNOUT (LBS)	—	502,000	218,000 (WITH P/L)
PAYLOAD (LBS)	—	—	25,000 (OR 50,000)
$I_{SP}$ (SEC)	—	425	460
$\Delta V$ (270 N.M./55 <sup>0</sup> INC)(FPS)	32,000	14,500	17,500
DEORBIT $\Delta V$ (FPS)	—	—	500

#### PAYLOAD DELIVERY AND RETURN CAPABILITY

A Space Shuttle will have a nominal mission of a round-trip payload to and from an orbit at 55°/270 nm. If the cargo is to be carried only one way, or if the destination orbit is different, the orbiter's payload capability will vary. In particular, the Space Shuttle can be employed for delivering satellites into their orbits or returning them from their orbits. Some possible missions of this type are represented on the accompanying chart which illustrates contours of up and down payload (in pounds) as a function of circular orbit altitude and inclination. The 25K Shuttle is shown to be capable of delivering the major astronomy satellites to their orbits, as well as returning them to earth. It is not capable, however, of reaching the sun-synchronous orbits around 100°/600 nm. The 50K Shuttle is capable of delivering and returning meteorology satellites to and from these sun-synchronous orbits.

PAYLOAD DELIVERY AND RETURN CAPABILITY



- = SATELLITE CAN BE DELIVERED AND RETURNED
- x = SATELLITE CANNOT BE DELIVERED OR RETURNED

## PAYLOAD PLACEMENT CAPABILITIES FROM COPLANAR 100 NM CIRCULAR ORBIT

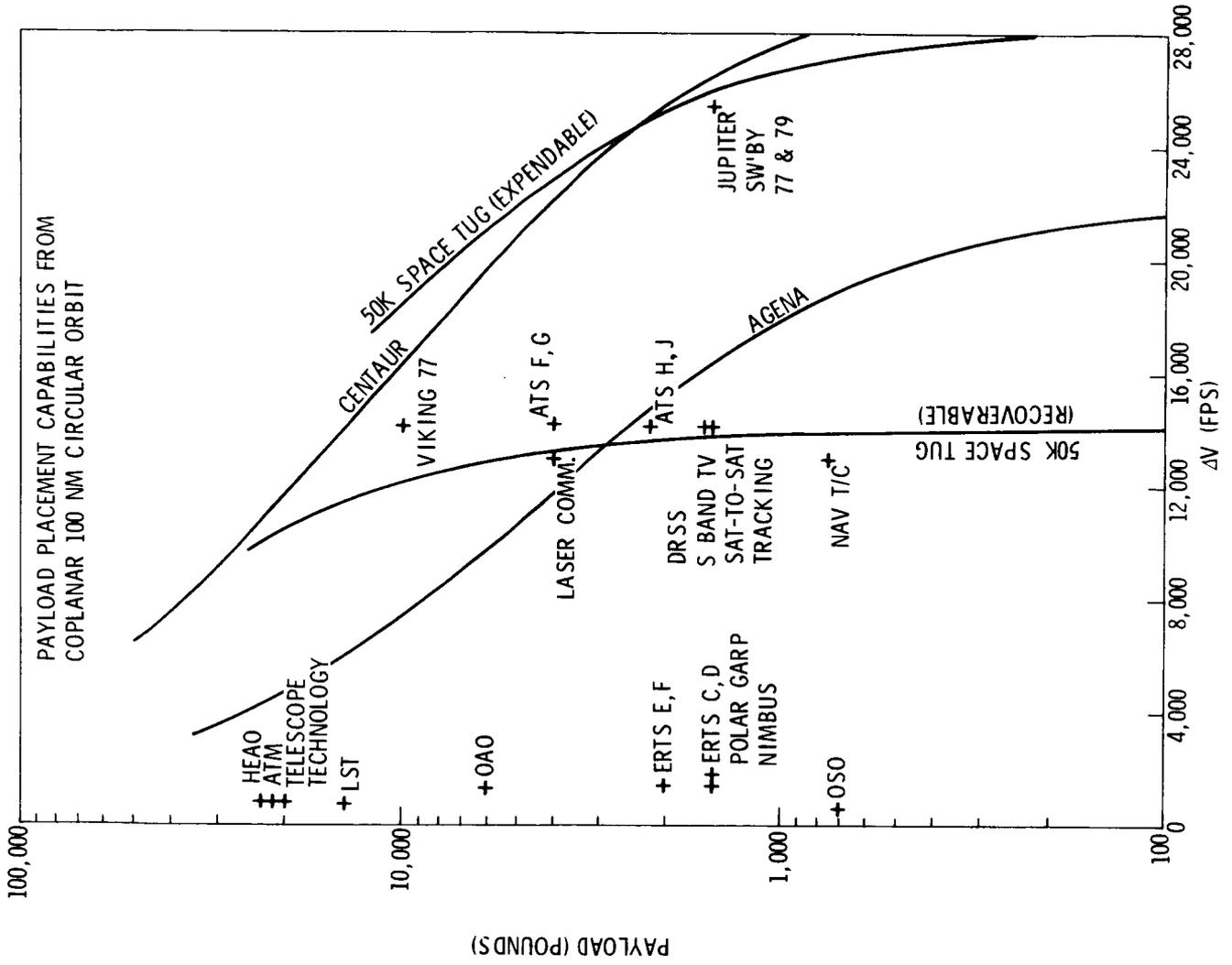
The addition of an upper propulsive stage - such as an Agena, Centaur, or a recoverable Space Tug with a 50,000 pound gross weight and propellant fraction  $\lambda = 0.85$  - significantly extends a Space Shuttle's capability for payload delivery, as is shown on the accompanying chart.

The mode considered here is that a Shuttle delivers the stage and payload to a circular reference orbit 100 nm high and coplanar with the destination orbit. The stage then continues and places the payload into its orbit.

If the stage is an Agena, it can deliver all astronomy, earth resources and meteorology satellites, and many, but not all, geosynchronous satellites. The remaining geosynchronous satellites would require a Centaur. A Centaur is also capable of launching Viking and outer planet missions. The payload delivery capability of an expendable Space Tug is essentially the same as that of a Centaur for these missions.

Note that the recoverable Tug is not able to reach an equatorial, geosynchronous orbit. This is because the Space Shuttle cannot attain a reference orbit of inclination less than 28.5° out of KSC without substantial payload penalties. The Tug has enough propellant to reach geosynchronous altitude but not enough to make the required 28.5° plane change. On the other hand, two Tugs used in a staged mode (both recoverable) can deliver 20,800 pounds, or return 7,400 pounds, or carry a round-trip payload of 5,400 pounds to and from an equatorial geosynchronous orbit.

Thus, whereas the Laser Communication Satellite or the Navigation & Traffic Control Satellite, which do not need to go into an equatorial orbit, can probably be launched using a single recoverable Tug, placing ATS and other communication and tracking satellites would require two staged Tugs.

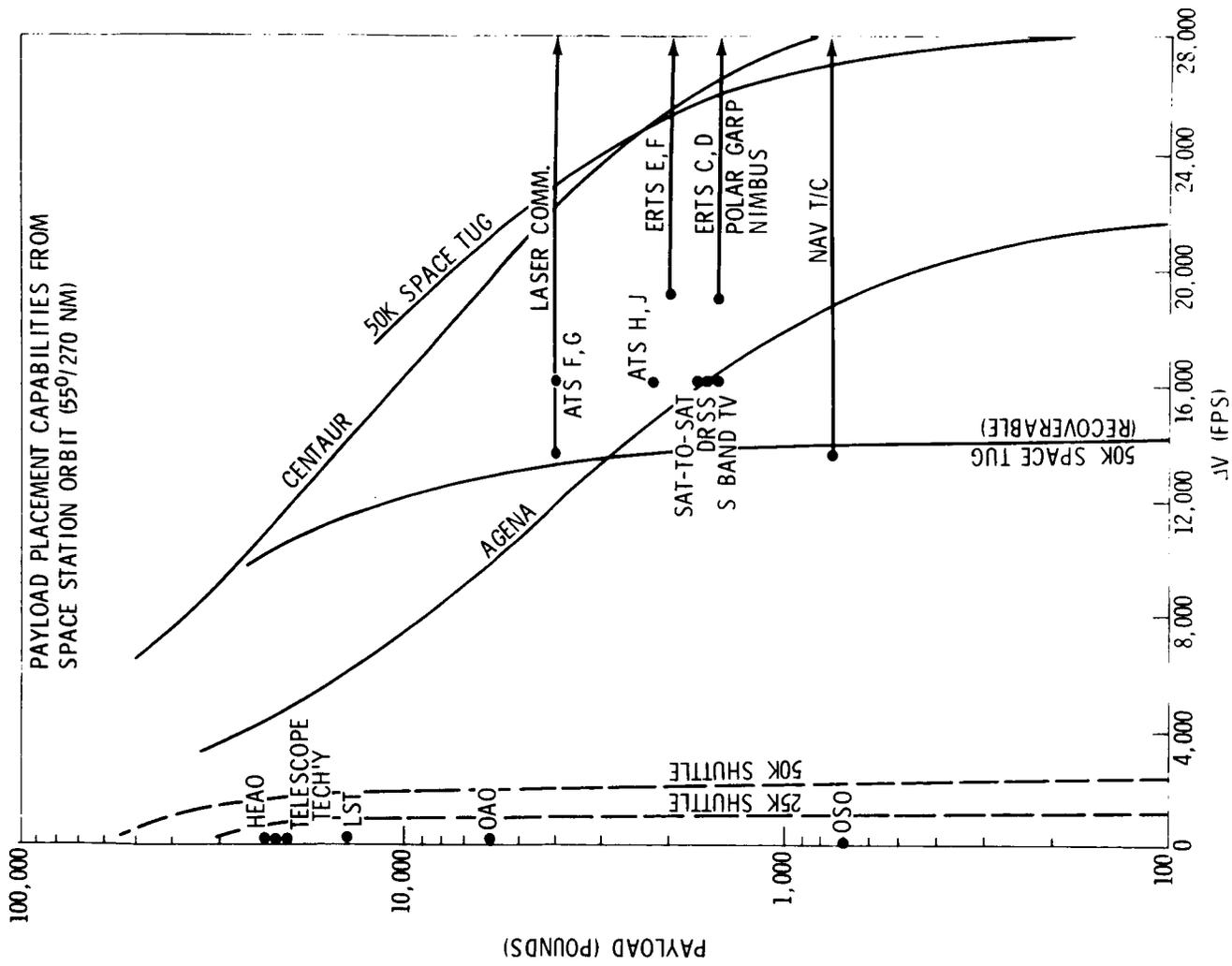


PAYLOAD PLACEMENT CAPABILITIES FROM SPACE STATION ORBIT  
(FOR SATELLITES COSTING OVER \$25M)

An alternate mode of satellite placement would be for the upper stages to operate from the vicinity of the space station at  $55^{\circ}/270$  nm. This might be the situation if the basic Shuttle mission included both space station logistics and satellite delivery on the same flight. Since all orbits (except equatorial orbits) will have a nodal precession rate which is different from the rate of the space station orbit, the  $\Delta V$  requirements to reach those orbits will vary with time, as indicated by the horizontal arrows on the chart. However, for payload placement only the lower bound applies since placement can be scheduled at the appropriate time. The astronomy satellite orbits have been placed coplanar with the space station for this operating mode. There is considerable flexibility in their orbit inclination, and coplanar alignment will reduce the  $\Delta V$  requirements for delivery from the space station site.

Astronomy satellites can be delivered without an upper stage because they have been placed in the space station orbit. Use of Agena adds the capability to deliver some geosynchronous satellites. A Centaur would be required to deliver the remaining geosynchronous satellites and all of the sun-synchronous satellites.

While all the satellites shown can be delivered with a Centaur, this cannot be done at any time. The required  $\Delta V$  moves back and forth with time along the horizontal arrows, and at some times the plane change maneuver is too large even for the Centaur.



### SOME POSSIBLE MULTI-SATELLITE MISSIONS

The performance of multipurpose missions would enhance the economic benefits of a Space Shuttle. On the accompanying chart are listed several possible missions which a Shuttle could perform with or without an upper stage. For example, a 25K Shuttle can make an inspection/repair tour of three major astronomy satellites if they are in coplanar orbits. With two Agenas onboard, a 25K Shuttle can launch Global Atmospheric Research Program (GARP) satellites to geostationary and to low altitude equatorial orbits, then visit an Orbiting Astronomical Observatory (OAO) in a 28.5° inclination orbit; with three Agenas onboard, it can launch three communication class satellites to geosynchronous altitude.

If the High Energy Astronomy Observatory (HEAO) and OAO are in coplanar orbits at 28.5°, then a 25K Shuttle can launch the HEAO and return the OAO, or even the heavier Large Space Telescope (LST). If a 50K Shuttle is used for the same mission, the orbit planes can be separated by as much as 6°. (This plane change could be due to an inclination difference, a node separation, or both.) A 50K Shuttle could also launch one Earth Resources satellite to sun-synchronous orbit and return another to the ground.

SOME POSSIBLE MULTI-SATELLITE MISSIONS

MISSION

REQUIREMENTS

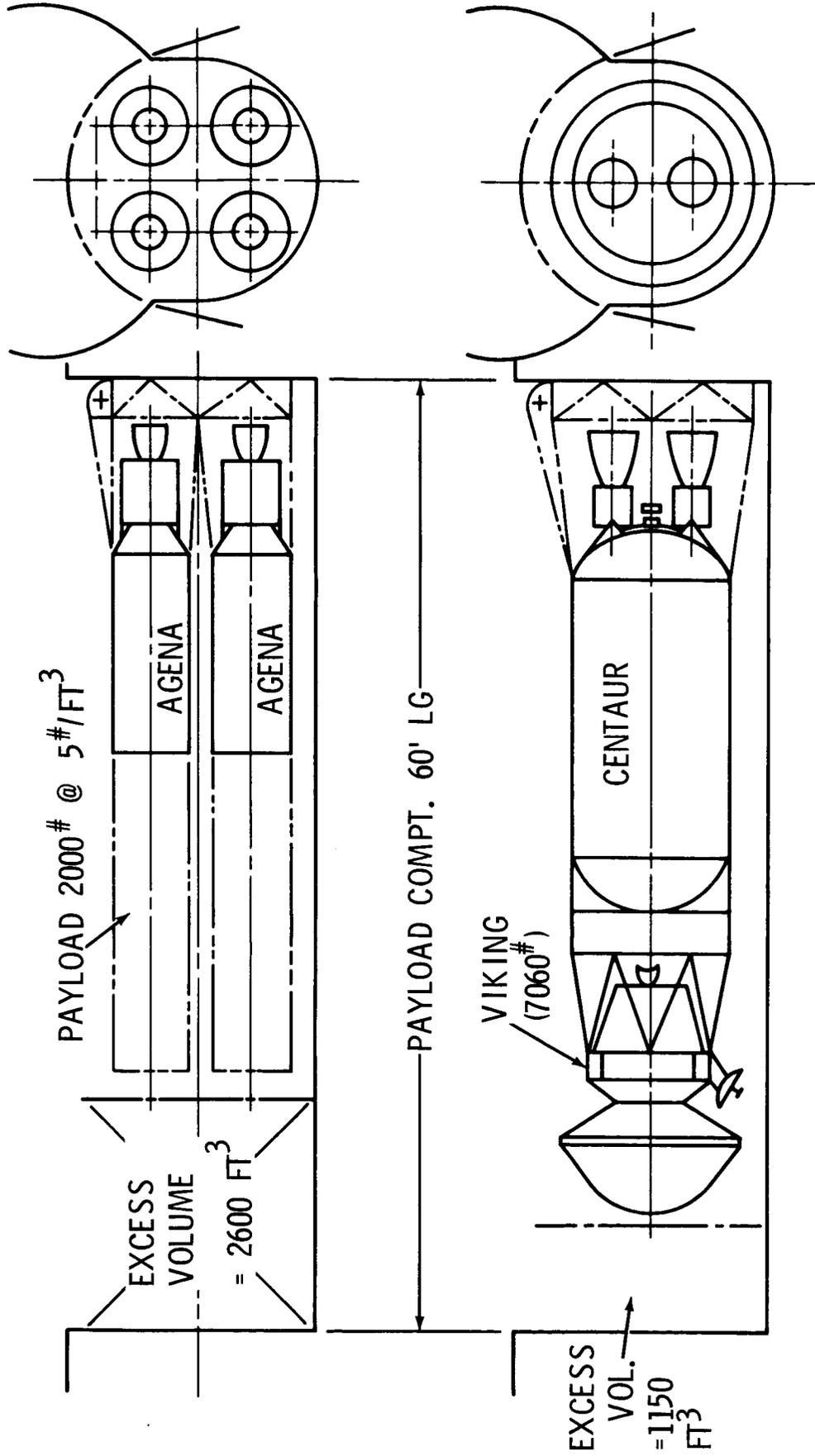
- |   |   |
|---|---|
| 1. VISIT HEAO; VISIT LST; VISIT OSO     | 25K SHUTTLE; COPLANAR ORBITS @ 28.5°            |
| 2. LAUNCH LOW ALTITUDE GARP;            | 25K SHUTTLE WITH 2 AGENAS;                      |
| LAUNCH GEOSTATIONARY GARP;              | OAO @ 28.5°                                     |
| VISIT OAO                               |   |
| 3. LAUNCH S-BAND TV;                    | 25K SHUTTLE WITH 3 AGENAS                       |
| LAUNCH ATS-H;                           |   |
| LAUNCH DRSS                             |   |
| 4. LAUNCH HEAO; VISIT & RETURN OAO      | 25K SHUTTLE; COPLANAR ORBITS @ 28.5°            |
|   | 50K SHUTTLE; HEAO @ 28.5°, $\Delta i < 6^\circ$ |
| 5. LAUNCH HEAO; VISIT & RETURN LST      | 25K SHUTTLE; COPLANAR ORBITS @ 28.5°            |
| 6. LAUNCH ERTS-C; VISIT & RETURN ERTS-B | 50K SHUTTLE; COPLANAR ORBITS @ 100°             |

#### SHUTTLE PACKAGING CAPABILITY

The accompanying chart shows that up to four Agena stages can be packaged into the cargo bay of a Shuttle orbiter, each with an unspecified payload attached. The size and shape of the excess cargo volume depends on the size of the Agena payloads. A Centaur stage is also shown in the cargo bay, with a Viking spacecraft attached.

The propulsive stages are held in place by a support structure which is pivoted to allow stage deployment when the orbiter has reached the reference orbit, as previously described.

# SHUTTLE PACKAGING CAPABILITY



## SHUTTLE CAPABILITY SUMMARY

The capability of a Space Shuttle for delivering, visiting, and returning satellites can be summarized as follows:

- A 25K Shuttle can provide direct delivery of all astronomy and bioscience satellites and 1/3 of the NASA and 2/3 of non-NASA earth observation satellites. Adding an Agena performs most earth orbital missions, and adding a Centaur performs all missions, including planetary launches, shown in the mission model.
- A 50K Shuttle adds direct delivery capability of 1/3 of the space physics satellites and the remaining NASA earth observation satellites.
- If the Shuttle goes to the space station orbit, only co-orbiting astronomy satellites can be delivered directly. In this case the 50K Shuttle shows no advantage over the 25K Shuttle.
- From the space station orbit, all satellites costing over \$25M can be delivered with a Centaur stage. If the direction of the line of nodes is important (as with some meteorology satellites), it may be necessary to wait for the proper relative alignment of nodes to stay within the Centaur capability.
- Multiple satellite delivery/visit/return missions are feasible.
- Although a single 50,000 pound Space Tug cannot attain geostationary orbit from 28.5°/100 nm, two such Tugs in a staged mode can deliver or recover all payloads planned for geostationary orbit.
- All satellites which can be delivered directly can also be recovered directly. On the other hand, some payloads which the Shuttle cannot deliver directly could still be recovered directly. This is due to the low deorbiting  $\Delta V$  (<500 fps) relative to the  $\Delta V$  required to reach orbit (17,500 fps for the orbiter stage). Although there are currently no satellites in this range, this feature may become important for some high inclination satellites (e.g., meteorology satellites) weighing much in excess of 20,000 pounds.

ORBITING ASTRONOMICAL OBSERVATORY

This section contains a description of possible OAO configurations and mission plans for the next ten years. An approach is indicated for changing the existing plan to fit the Shuttle program and use the Shuttle to guarantee the diversity and lifetime of a comparably equipped ground-based telescope. The primary change in the existing OAO program involves replacing the series of unmanned satellites, having telescopes with increasingly larger apertures, with a single, man-maintained and uprated telescope designed for Shuttle delivery to orbit and return to the ground for major repairs, adjustments, and changes in the mirror figure.

## OAO CONFIGURATION AND PROGRAM PLAN

The chart on the opposite page illustrates the advanced OAO configuration (E, F, and G).

The two figures below indicate the currently planned launch schedule and some of the characteristics of the OAO program as it might exist in the absence of the shuttle. The payload characteristics reveal a stepwise approach to achieving the 120" telescope through a series of smaller telescopes using basically the same technology.

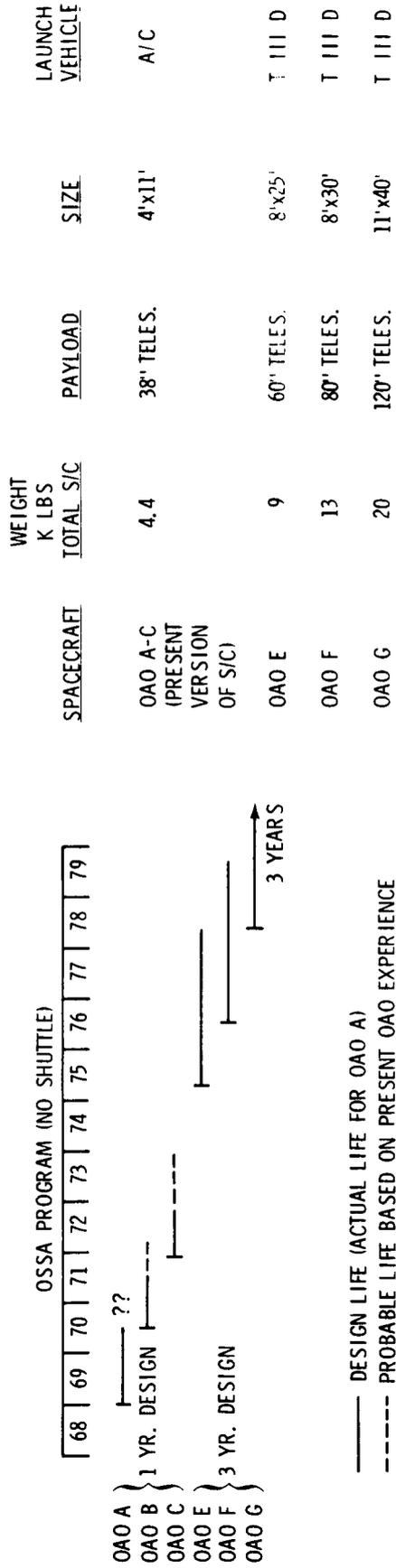
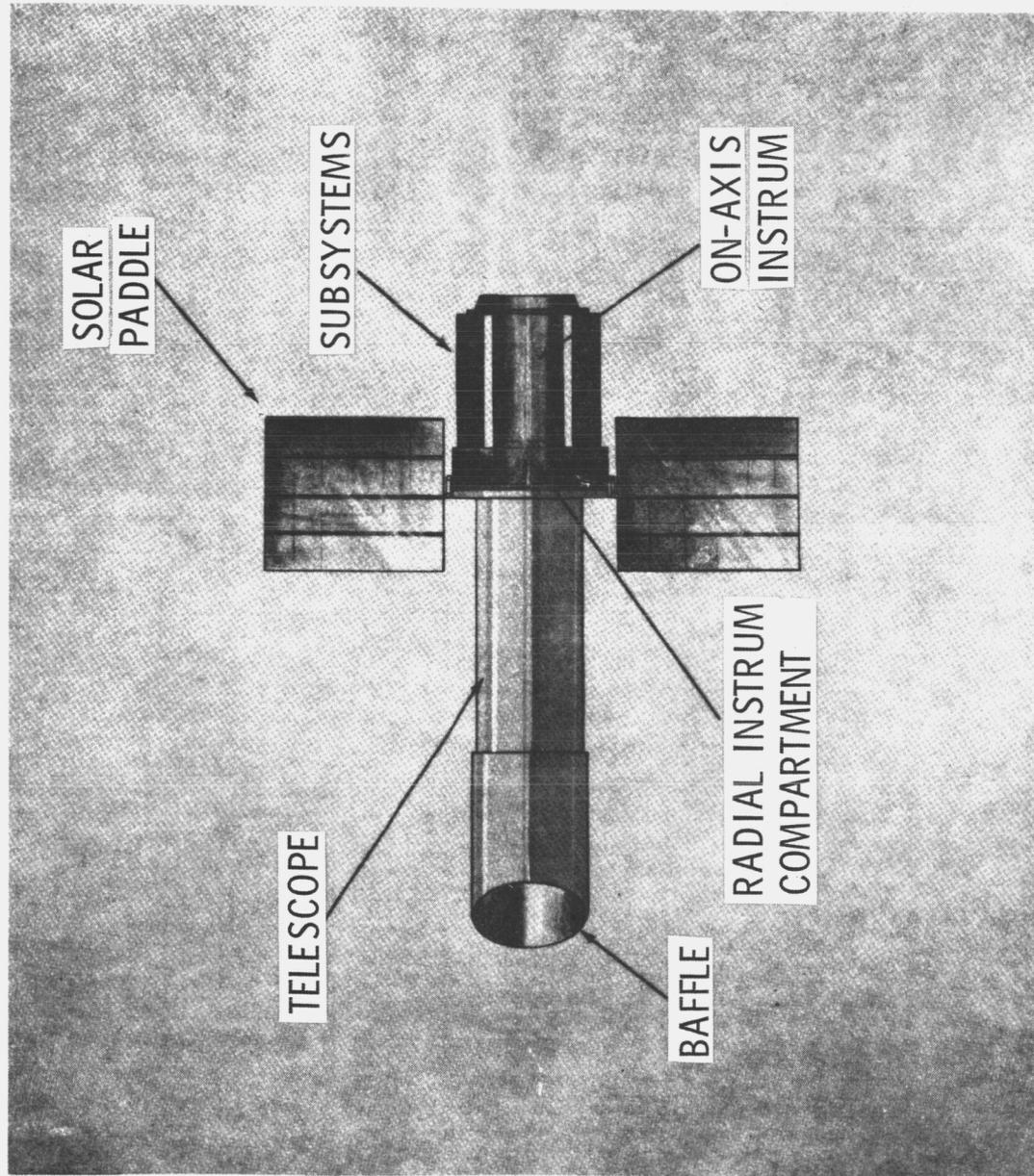


FIGURE 1 - OAO LAUNCH SCHEDULE

FIGURE 2 - PROGRAM RECOMMENDED BY OAO PROJECT

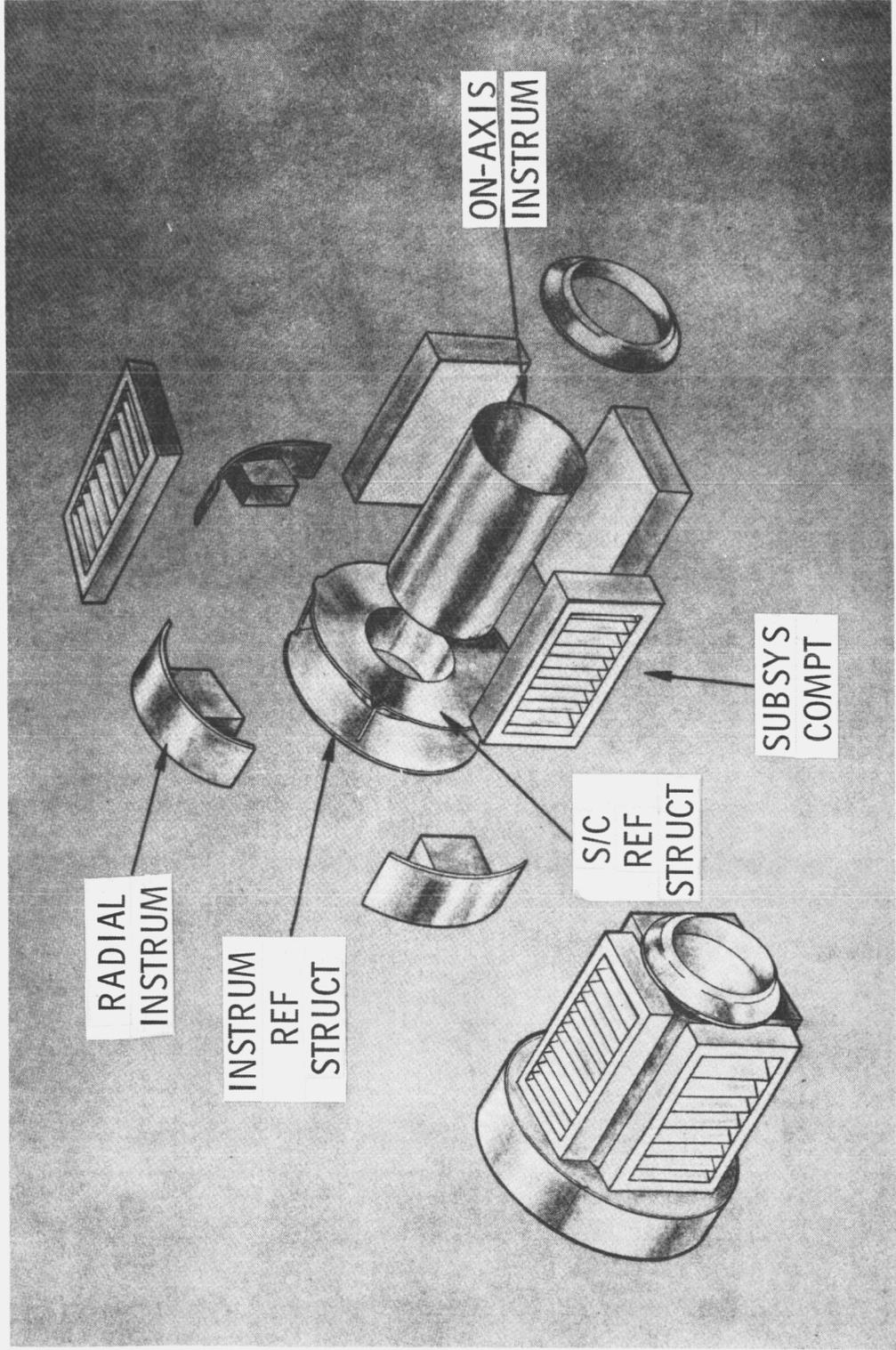
TYPICAL ADVANCED OAO CONFIGURATION



## MODULAR CONCEPT FOR OBSERVATORY INSTRUMENTS AND SUBSYSTEMS

The OAO Project has looked into modular concepts for advanced spacecraft design. This chart suggests a modular version of the subsystems compartment. Photographers would be typical radial instrumentation while a spectrometer would be in the on-axis instrument compartment. Replacement of these modules for repair or updating purposes could be accomplished through either a manned or unmanned satellite visit mode.

MODULAR CONCEPT FOR OBSERVATORY INSTRUMENTS  
AND SUBSYSTEMS



## ORBITAL OBSERVATORY PROGRAM CHARACTERISTICS

The following two charts compare several aspects of two different program alternatives for OAO. The alternative shown in the NASA long range plan employs a series of telescopes of increasing size, culminating in the 120" facility, with the possibility of orbital maintenance, but no recovery. Each satellite in this series is built to achieve its maximum operational performance as soon as it is launched, with on-orbit repair possible to maintain that performance. With the planned launch schedule and anticipated lifetimes, more than one satellite will be operational on several different occasions.

In the program alternative proposed to take advantage of the Shuttle capabilities, the series of advanced OAO spacecraft is replaced by a single spacecraft carrying the 120" telescope. The suggested program to use this telescope involves a series of engineering tests of payload performance in earth orbit followed by the necessary orbit revisits and recovery/relaunch missions for improvement in the payload design until the goal of diffraction limited performance in the UV is achieved. Possible advantages of this program alternative include cost (one spacecraft instead of three) and performance (zero g effects on large mirrors may not be predictable without an actual on-orbit engineering test followed by ground refurbishment). Another way of viewing this situation is that, in view of the high cost per spacecraft, it may not be reasonable to count on having more than one advanced OAO in the decade. If there is only one instrument, one would like reasonable assurance that it would serve the needs of astronomy for at least several years (preferably more), so that there would be an appropriate return on investment. The Shuttle offers the most complete form of guarantee, providing the capability for both on-orbit repair and, if necessary, recovery and relaunch. The question of whether it is the most economic form of guarantee remains to be determined.

ORBITAL OBSERVATORY PROGRAM CHARACTERISTICS

OAO PROJECT PROPOSAL

1. SERIES OF OPERATIONAL TELESCOPES (60", 80", 120") AT ~\$100 M EACH, ORBITAL MAINTENANCE, NO RECOVERY
2. NO PLANNED IN ORBIT TEST OF MIRROR FIGURE OR OPTICAL SYSTEM PERFORMANCE
3. DESIGN GOAL IS DIFFRACTION LIMITED PERFORMANCE EQUIVALENT TO A SYSTEM WITH A SMALLER APERTURE.
4. SCIENCE IMPROVED BY SMALL INCREASES IN TELESCOPE SIZE USING SAME BASIC DESIGN
5. STEADY SCIENCE OUTPUT FROM 2-3 TELESCOPES OPERATING SIMULTANEOUSLY
6. PAYLOAD DIVERSITY THROUGH MULTIPLE LAUNCHES AND IN ORBIT MODULE REPLACEMENT

ORBITAL OBSERVATORY PROGRAM CHARACTERISTICS

PROPOSAL TO TAKE ADVANTAGE OF SHUTTLE

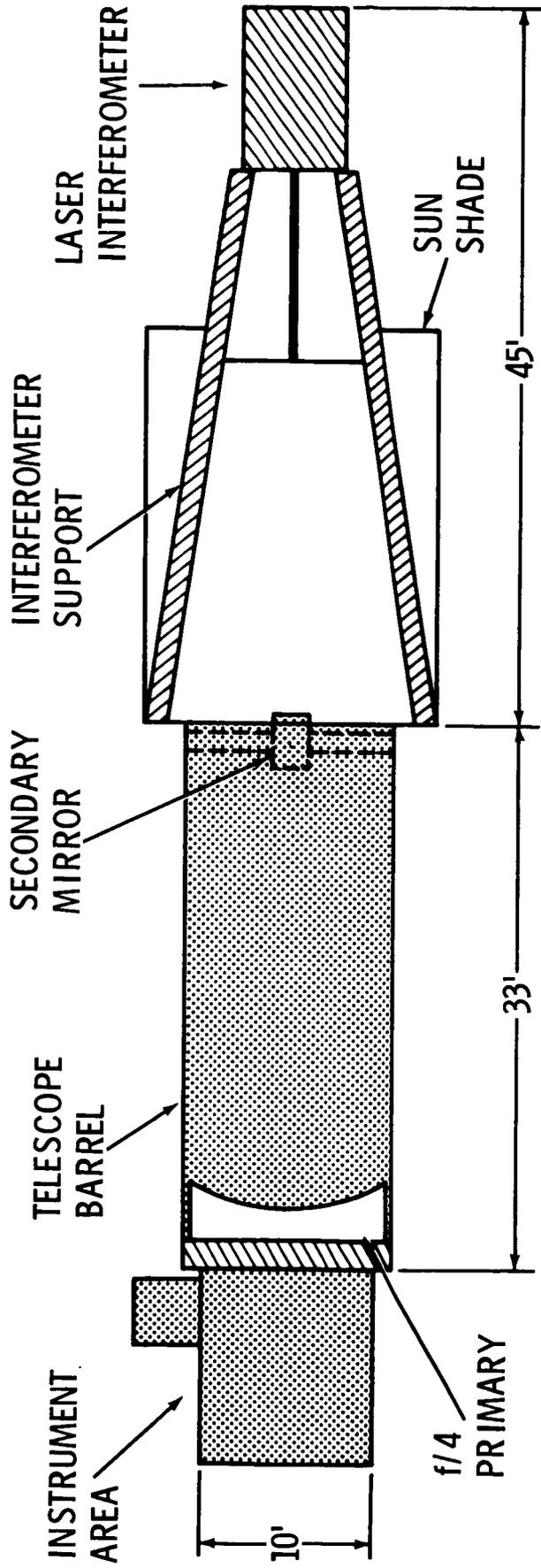
1. ONE DEVELOPMENTAL 120" TELESCOPE, UPGRADE DURING EARTH RETURN PHASE, THEN REORBIT
2. IN ORBIT TESTING OF TELESCOPE QUALITY
3. DESIGN GOAL IS 120" DIFFRACTION LIMITED PERFORMANCE IN UV
4. SCIENCE IMPROVED BY REFIGURING EXISTING SYSTEM
5. INTERRUPTED SCIENCE OUTPUT DURING ORBITAL TESTS AND GROUND UPGRADING
6. PAYLOAD DIVERSITY THROUGH GROUND RETURN CYCLE AND IN ORBIT MODULE REPLACEMENT

## TELESCOPE IN TESTING CONFIGURATION WITH INTERFEROMETER ATTACHED

For the Shuttle-serviced OAO program, the primary engineering test of telescope quality in earth orbit involves the use of an attached laser interferometer. In the adjacent chart the telescope is shown in its orbital configuration with the interferometer attached. The figure of the mirror is determined in a systematic fashion to within  $1/50 \lambda$  or better by this method. Based upon on-orbit mirror figure measurements, the telescope mirror is refinished on the ground and returned to orbit with an improved figure. System optics are tested by the Hartmann Method, which does not require the interferometer. Instead, a Hartmann screen is placed in front of the primary mirror inside the telescope barrel.

As can be seen in the chart, the laser interferometer for the engineering test of the primary mirror figure is about as large as the telescope system. Therefore, it would require a separate launch by the Shuttle. Possible roles for astronaut EVA include attaching the interferometer and removing the secondary mirror for the primary mirror test, restoring the operating configuration, and installing and removing the Hartmann screen.

TELESCOPE IN TESTING CONFIGURATION WITH INTERFEROMETER ATTACHED



TESTING PROCEDURE FOR DIFFRACTION LIMITED PERFORMANCE

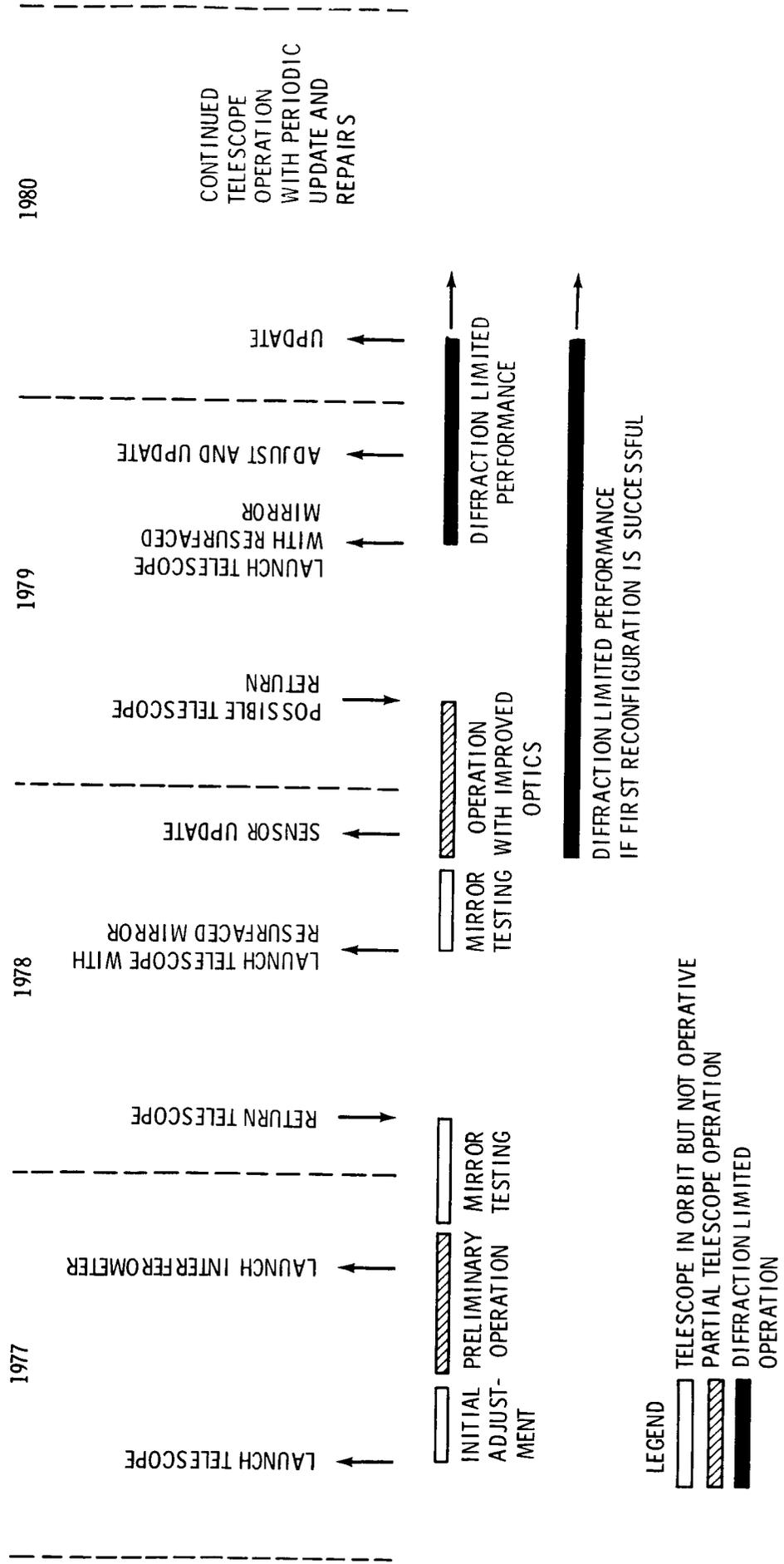
- a) PRIMARY MIRROR TESTED WITH INTERFEROMETER
- b) SYSTEM OPTICS TESTED BY HARTMANN METHOD
- c) ALL MIRROR FINISHING AND COATING DONE ON GROUND
- d) MAJOR SUBASSEMBLIES ( INTERFEROMETER, SYSTEM TESTING EQUIPMENT, DETECTORS, SPECTROMETERS) ATTACHED IN ORBIT

## TIMELINE FOR SHUTTLE/TELESCOPE OPERATIONS

The timeline is indicated for the Shuttle-serviced OAO program. Note that some limited observing is anticipated prior to the launch of the interferometer and subsequent mirror testing. Sensor updating is anticipated once a year to take advantage of system improvements and changes in observing priorities. The return of the telescope in 1978 and 1979 may allow minor changes in the telescope structure (thermal control, power supplies, etc.) as well as those required for mirror modification.

This timeline assumes that the Shuttle is operational in 1977. The question of the economy of using the Shuttle in this type of program will be addressed later in sections on the traffic model and concluding issues.

TIMELINE FOR SHUTTLE/TELESCOPE OPERATIONS



## ADVANTAGES OF THE SHUTTLE MODE

The advantages of the Shuttle-modified OAO program range from those which would benefit any payload (minimal size restriction) to those which are of primary importance to an observatory facility. Most important is the recovery capability of the Shuttle. This is the only way modifications to the mirror figure can be made as well as major modifications to satellite subsystems.

Fundamental to the question of diffraction limited performance in zero-g is the issue of the predictability of changes in mirror deformation after being ground in 1-g and launched through a 3-g environment.

At the present time it appears that microstrains occur in the mirror surface during polishing. The surface layer may not be elastically deformable and, therefore, the final figure would be non-predictable. If this does in fact prove to be the case, mirror refinishing in orbit must be considered. This would represent a major task for man in orbit which has not been addressed here.

## ADVANTAGES OF SHUTTLE MODE

### SHUTTLE VEHICLE CONSIDERATIONS

- T-3D SHROUD SIZE  
MAY CONSTRAIN 120"  
TELESCOPE DESIGN

### REPAIR AND UPDATE

- SENSOR  
REPLACEMENT
- ELECTRONIC  
MODULE REPLACEMENT
- CRYOGENIC  
REPLENISHMENT FOR  
IR DETECTORS

### RETURN TO EARTH

- MIRROR  
REFINISHING
- MODIFICATION  
TO SPACECRAFT  
SYSTEMS

### EVA DEPLOYMENT

- INTERFEROMETER  
ATTACHMENT
- REMOVE AND  
REPLACE SECONDARY  
OPTICS
- EMPLACE APERTURES  
FOR HARTMANN  
TEST

## ISSUES

- WILL PRIMARY MIRROR SHAPE RECOVER AFTER 0g - 1g - 0g TRANSFER THROUGH 3g's
- CAN MIRROR RESURFACING BE DONE IN ORBIT

HIGH ENERGY ASTRONOMY OBSERVATORY (HEAO)

Unlike OAO, the HEAO is a new satellite concept which is just now entering the early stages of definition. A number of different payload concepts are under discussion between NASA (OSSA) and the high energy physics and astronomy community.

The payload concept presented here is an advanced design employing a super-cooled magnet. This concept has previously been proposed for flight on a space station experiments module. For the purposes of this study it has been assumed that this payload could be flown either on a conventional rocket-launched satellite or as a satellite which is delivered, serviced and recovered by the Shuttle.

The objective here is to cite the possible advantages of the Shuttle mode. In many respects the proposed payload has been tailored to capitalize on Shuttle characteristics. The advantages (e.g., size, weight) accrued through proper design for the Shuttle mode are discussed in terms of their scientific value.

## HEAO SATELLITE FUNCTIONAL ELEMENTS

This chart illustrates a Shuttle payload for the study of high energy cosmic rays and their interaction with matter. The design is based on previous work describing a space station facility for carrying out high energy cosmic ray research. (1,2) The main element of this system is a magnetic spectrometer for measuring the energy of primary charged particles. The configuration shown here, while not unique, makes full use of the Shuttle potential. A liquid hydrogen target can be placed at various locations, providing a capability for performing significant high energy physics research. The Total Absorption Nuclear Cascade (TANC) spectrometer is used to measure the summed energy of the charged particles and neutrals (secondaries) produced when an energetic primary proton collides with the target nuclei. The magnetic spectrometer, depending on target location, can be used to measure the primary particle's energy with momentum analysis of the secondaries or for momentum analysis of the secondaries only. The TANC spectrometer is used for total energy measurement.

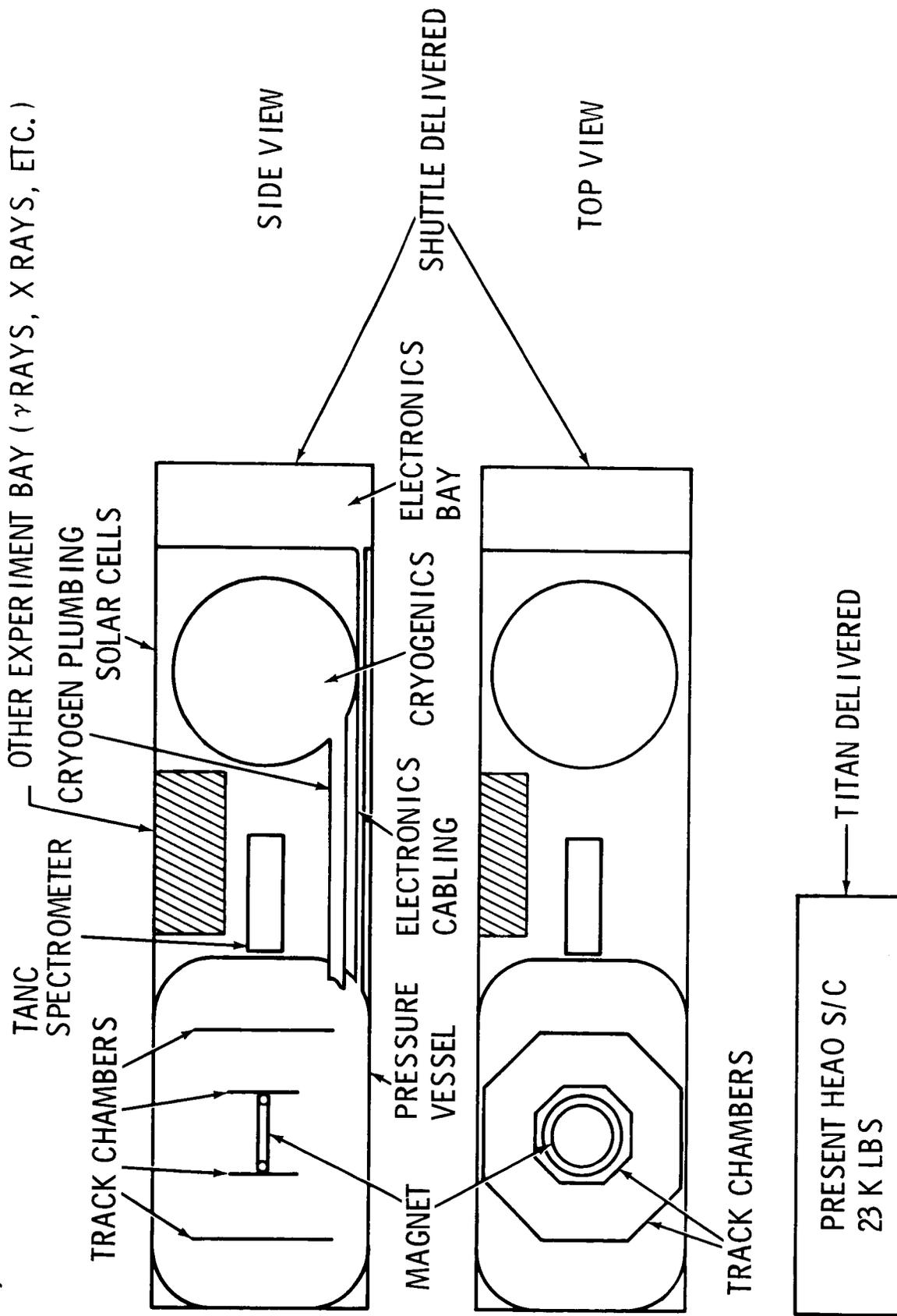
Given the earth return potential of this payload, liquid helium can be replenished on a periodic basis, obviating the need for a refrigerator and its large power requirements. The use of solid hydrogen for cooling purposes could realize a large increase of the in-orbit capability of this system.

A modular bay for smaller and shorter lived experiments can be made available. This will provide a quick turn-around capability for a variety of research purposes. The entire module, perhaps containing several experiments for x-ray and  $\gamma$ -ray observations, could be replaced on a regular basis either for repair or for changing the complement of instruments.

The relative size of the presently proposed Titan-delivered HEAO is illustrated by comparing the top and bottom figures in the chart.

1. L. Kaufman, "Cosmic Ray and High Energy Physics Studies in Space," Bellcomm, Inc., TR-69-103-1 (1969).
2. L. Kaufman, "An Approach Toward the Implementation of a High Energy Physics Cosmic Ray Facility in Space," TM-69-1015-4 (1969).

HEAO SATELLITE FUNCTIONAL ELEMENTS

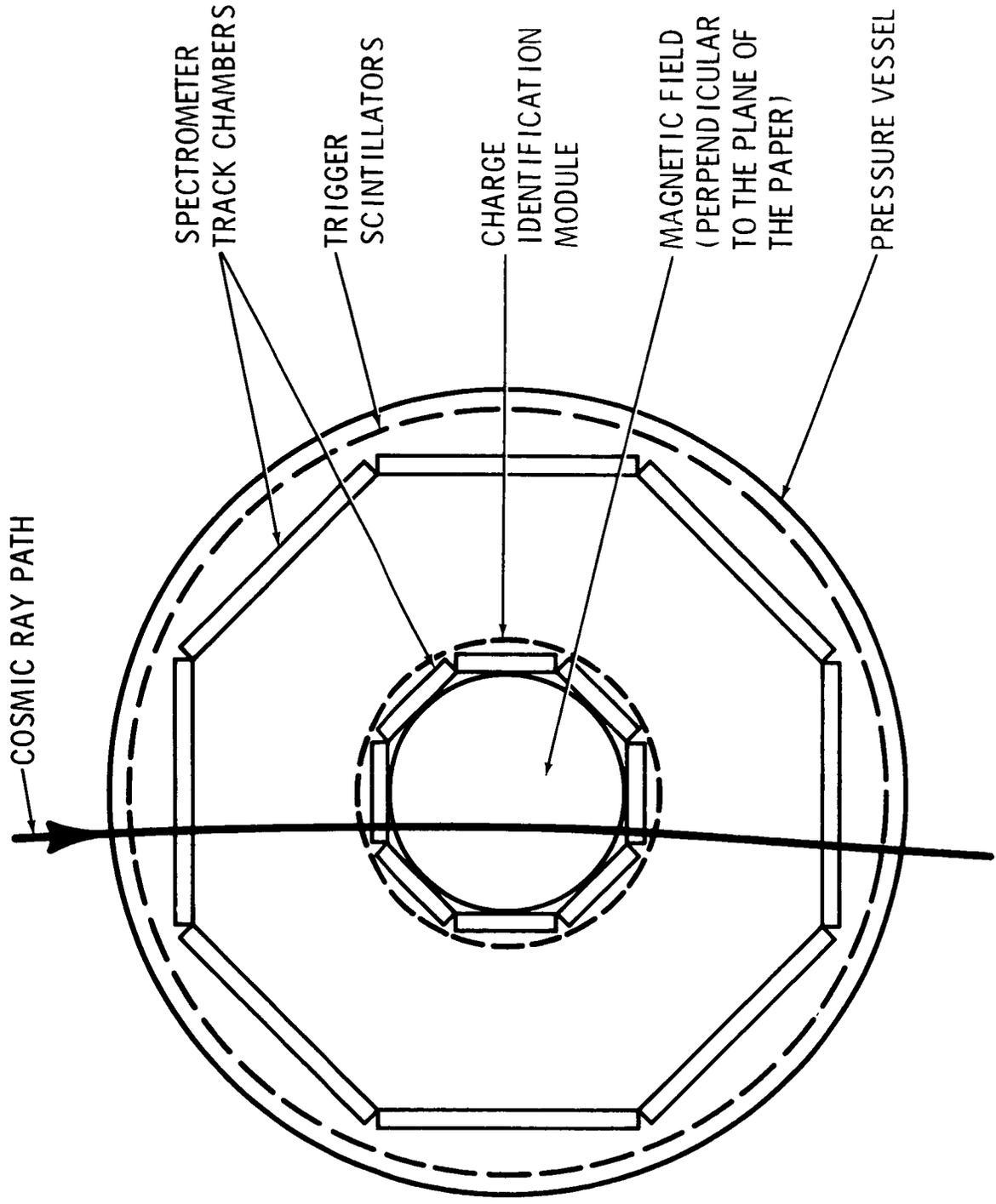


## EXPANDED TOP VIEW OF THE MAGNETIC SPECTROMETER

The central superconducting magnet provides a field which bends the path of charged particles. High location accuracy track chambers measure the incoming and outgoing paths, thus providing coordinates that, together with an accurate map of the magnetic field, yield the momentum to charge ratio of the particle. The charge can be determined independently by measuring the particle's energy loss in various materials.

Triggering is performed by fast logic analysis of the pulse correlations in the trigger scintillators. In addition, pulses from the charge identification modules can be used to minimize accidental triggering. The logic system for this is discussed in Ref. 2. Since it is likely that the track chambers used will operate within a gaseous (or liquid) medium, a pressure vessel becomes necessary to maintain an adequate environment.

EXPANDED TOP VIEW OF THE MAGNETIC SPECTROMETER



## SCIENCE RETURNS ASSOCIATED WITH SPACECRAFT GEOMETRY AND WEIGHT CAPABILITY

The accumulation of meaningful statistics is one of the most vexing problems of high energy cosmic ray research. Larger volumes allow for increases in the size of the magnet and for larger cryogen supplies, thus increasing useful area and exposure time.

The resolution of the system also improves. Larger magnets can be used, thereby increasing the magnetic field and amount of bend. The diameter of the magnetic spectrometer can be thought of as a lever which increases the accuracy with which the bend can be measured.

For the large payloads being considered here, the spectrometer configuration is independent of size and is simply scaled up or down to fit the available volume and weight allowance. The additional experiments considered for the modular bay cover the field of x-ray and gamma-ray research, infrared measurements, etc.

HEAD

SCIENCE RETURNS ASSOCIATED WITH SPACECRAFT GEOMETRY AND WEIGHT CAPABILITY.

- STATISTICS (SCIENCE VALUE)  $\sim$  (MAGNET DIAMETER)<sup>2</sup>  $\times$  TIME
- RESOLUTION (SCIENCE VALUE)  $\sim$  MAGNET MASS  $\times$  LEVER ARM.
- OPTIMUM CONFIGURATION IS (ROUGHLY) SIZE INDEPENDENT, ONLY SCALE FACTOR VARIES.
- ADDITIONAL EXPERIMENTS IN MODULAR BAY

## HEAO PROGRAM CHARACTERISTICS

This chart compares certain programmatic aspects of two different plans for HEAO missions. The OSSA plan, as illustrated in the introduction to this paper, envisions a series of four satellites, probably with different payloads, flown in consecutive years beginning in 1974. This schedule has been criticized by some scientists as being too cramped and therefore not allowing time for knowledge gained from early missions to influence the payload and mission plan for later flights.

The HEAO plan proposed for the Shuttle mode is based on the launch of a single satellite which would then be repaired and updated over an extended number of years. Changes to the satellite could be made on orbit or on the ground (with Shuttle recovery and relaunch), depending on the particular refurbishment requirements and the availability of appropriate on-orbit facilities and techniques.

The conventional satellite approach could, without question, produce earlier results; boosters are available now and the Shuttle is not. The proper tradeoff between conventional versus Shuttle-serviced satellites must include the appropriate economics, namely the cost of Shuttle flights and the cost of additional satellites. One possible solution to this question, using a particular set of cost assumptions, is illustrated in the Traffic Model section of this paper.

HEAO PROGRAM CHARACTERISTICS

OSSA PLAN (5 YEAR PROGRAM)

SERIES OF FOUR OPERATIONAL  
SATELLITES (~ \$100 M EACH);  
POSSIBLE ORBITAL MAINTENANCE

EARLIEST FLIGHT IN 1974

PRE-FLIGHT CHECK ON DETECTOR  
QUALITY

SCIENCE CONTINUITY LIMITED BY  
AVAILABILITY OF NEXT SATELLITE

SCIENCE RETURN LIMITED BY  
SATELLITE SIZE AND WEIGHT

DIVERSITY IN PAYLOAD THROUGH  
MULTIPLE SPACECRAFT

SHUTTLE IMPACT (EQUIVALENT 5 YEAR PROGRAM)

ONE OPERATIONAL SATELLITE; ORBITAL  
MAINTENANCE AND GROUND MAINTENANCE  
AND UPGRADING

EARLIEST FLIGHT IN 1977

PRE-FLIGHT AND POST-FLIGHT CHECK ON  
DETECTOR QUALITY

SCIENCE CONTINUITY LIMITED BY SHUTTLE  
AVAILABILITY AND GROUND REPAIR TIME

MORE VOLUME; WEIGHT?

DIVERSITY IN PAYLOAD THROUGH  
GROUND AND ON ORBIT REPLACEMENT

## MAINTAINING AND UPGRADING HEAO

This chart identifies the major functional elements of the HEAO payload as the concept has been described in this paper. Each functional element has some assumed requirement for repair or replacement. Repair intervals cannot be predicted, but the indicated replacement intervals correspond to the evolutionary payload concept envisioned here.

The assumed operational mode for the Shuttle envisions on-orbit tasks limited to the replacement of modular units such as electronics or cryogen tanks. Tasks which require sensitive alignment or getting inside the pressure vessel are assumed to be better done on the ground. As pointed out earlier, though, this depends on what facilities can be made available on orbit.

MAINTAINING AND UPGRADING HEAO

I PAYLOAD FUNCTIONAL ELEMENTS

REQUIREMENTS

- CRYOGENS (LIQUID HELIUM) ● REPLACE ONCE/YEAR
- CRYOGENIC SYSTEM PLUMBING ● REPAIR AS NEEDED
- ELECTRONICS ● REPAIR AS NEEDED; UPGRADE BY REPLACEMENT IN ~ 5 YEARS
- CABLING ● NONE
- MAGNET (SUPER CONDUCTING) ● UPGRADE BY REPLACEMENT IN ~ 5 YEARS
- TRIGGER SCINTILLATOR PHOTOTUBES ● REPAIR AS NEEDED
- TRACK CHAMBERS ● REPAIR AS NEEDED; UPGRADE BY REPLACEMENT IN ~ 2 YEARS
- MODULAR EXPERIMENT BAY ● REPLACE IN 1 - 2 YEARS

II ACCOMMODATION OF REQUIREMENTS - ORBITAL VISIT MODE

- YES { ● REPLACE CRYOGENS
- REPAIR ELECTRONICS - ASSUMES MODULAR DESIGN
- REPLACE MODULAR EXPERIMENT BAY
- NO { ● REPAIR CRYOGEN PLUMBING - NOT MODULAR
- REPLACE TRIGGER SCINTILLATORS - INSIDE PRESSURE VESSEL
- REPLACE TRACK CHAMBERS - REQUIRE ALIGNMENT (30 $\mu$ ); INSIDE PRESSURE VESSEL

III ACCOMMODATION OF REQUIREMENTS - EARTH RETURN MODE

YES

#### RECOMMENDED SHUTTLE/HEAO MODE

Based on the assumptions listed at the top of this chart, the operational mode envisioned consists of a single satellite developed and run as an evolutionary experiment facility. Teams of scientists would conduct a variety of different experiments over a period of many years. The bulk of the payload would be designed as a more or less permanent structure with experiment peculiar detectors being changed to respond to new interests and new technology. The satellite would be returned to the ground every one to two years (for major repairs and to change detectors inside the pressure vessel). Interim visits for on-orbit repairs of modular elements (by replacement) could be accomplished through a Shuttle mode, perhaps using astronaut EVA, or through use of a remote teleoperator. Such a teleoperator could be delivered by the Shuttle or a conventional booster.

RECOMMENDED SHUTTLE/HEAO MODE

- SHUTTLE DELIVERED SPACECRAFT HAS SUFFICIENT VOLUME FOR ONE YEAR CRYOGEN SUPPLY
- ELECTRONICS EXPECTED TO SURVIVE AT LEAST ONE YEAR
- ALL OTHER MAINTENANCE AND UPGRADING REQUIREMENTS NOT ACCOMMODATED BY ORBITAL VISIT

THEREFORE

- PLAN FOR SATELLITE GROUND MAINTENANCE AND UPGRADING AT 1-2 YEAR INTERVALS
- INTERIM ORBITAL REVISIT FOR ELECTRONIC MODULE REPLACEMENT AND CRYOGEN RESUPPLY

NIMBUS-POTENTIAL IMPACT OF THE SPACE SHUTTLE  
ON UNMANNED SATELLITE DESIGN AND OPERATIONS

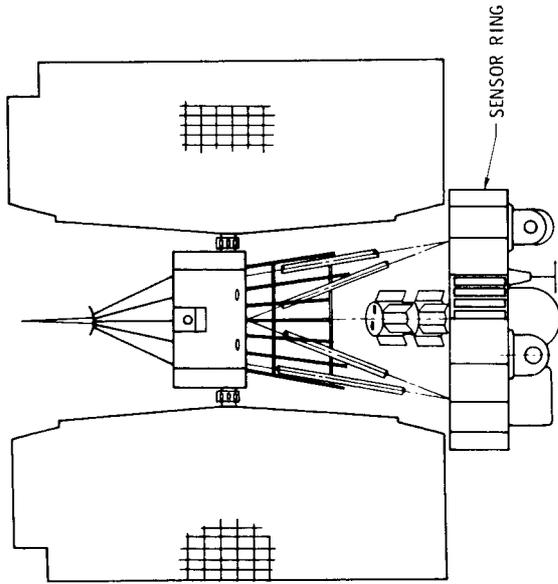
The Nimbus satellite, which is representative of the generic class of earth-viewing spacecraft, is shown reconfigured to accommodate satellite servicing for the purpose of assessing the impact of such servicing operations. The Nimbus, like many satellites, was designed using a modular approach with equipment mounted in separate bays, and with removable panels to assist in system orientation and installation. Nimbus was not configured for orbital servicing and, since it had to meet launch vehicle weight and shroud envelope constraints, was compact and as densely packaged as structural and thermal environments would permit. This design approach provides only the minimum degree of accessibility necessary for factory fabrication, testing, and adjustment.

In the reconfigured Nimbus the existing solar cells and batteries have been replaced by a Radioisotope Thermoelectric Generator (RTG) unit sized for peak power requirements ensuring a long power supply lifetime and freeing the satellite from solar panel orientation constraints. The sensors and subsystems have been grouped in two separate detachable modules with plug-in interface connectors. Subsystems have been packaged in individual, easily accessible compartments for servicing. Sensors can either be replaced individually on the sensor platform or the entire platform can be removed for major updatings.

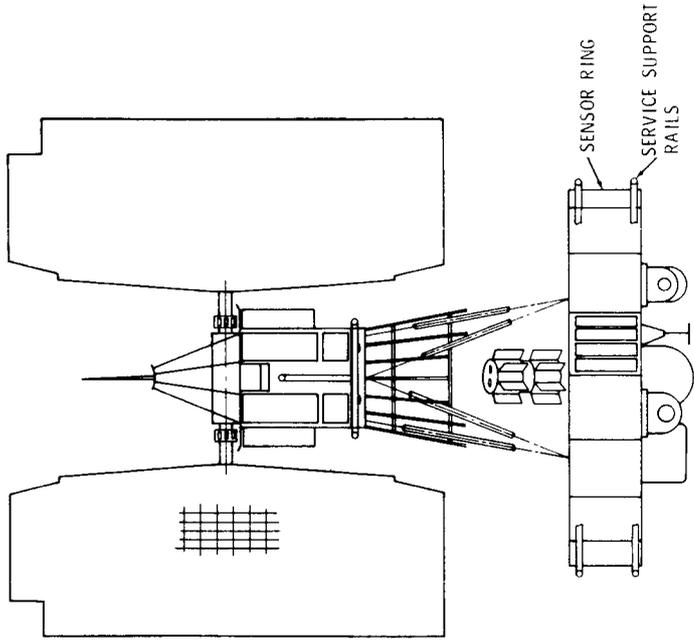
Satellite sensors and experiments share common systems support, namely, power, data transmission, command and control, pointing, environmental control, etc. Extending the reconfigured Nimbus concept, common carrier satellites can be conceived as limited extensions of existing satellites with a capability of accepting various sensors and subsystems within constrained interface tolerances. Such satellites would be unmanned space stations which could be modified to meet varying mission requirements. This would include a capability for modular additions or replacement of sensors, subsystems, and other payloads. Since earth-viewing sensors are of the same generic family, envelopes for supporting interfaces (power, ACS, telemetry, etc.) might in general be predictable for a broad range of sensor uprating requirements.

NIMBUS-POTENTIAL IMPACT OF THE SPACE SHUTTLE ON UNMANNED SATELLITE DESIGN AND OPERATIONS

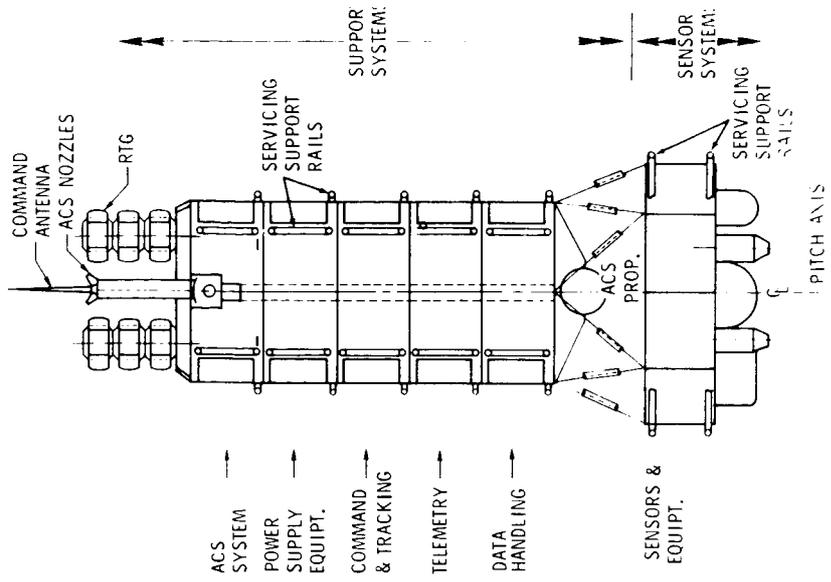
NIMBUS III AS PRESENTLY CONFIGURED



NIMBUS III EXPANDED CONFIGURATION



NIMBUS LONG TERM FACILITY



### INTERPLANETARY METEOROID SPACECRAFT

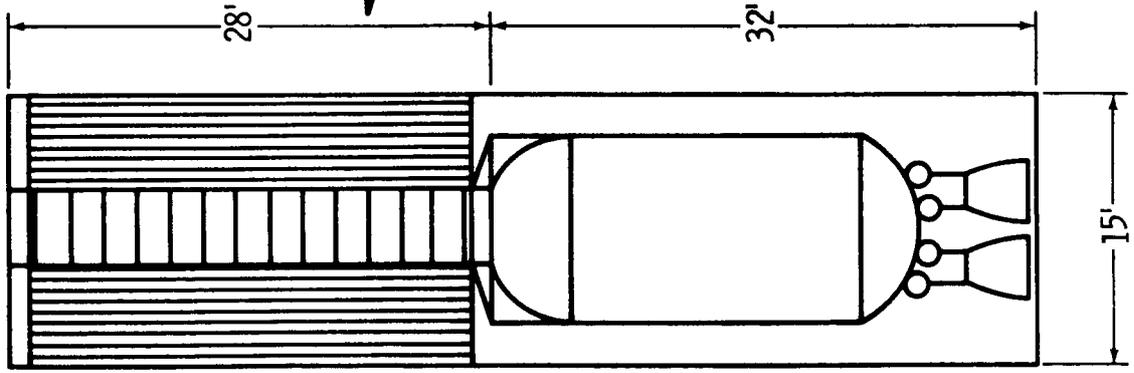
This section describes a new type of unmanned spacecraft which capitalizes on the large weight and volume capability of the Shuttle as a launch vehicle, and on its special capability to provide a man to aid in spacecraft deployment in orbit and to recover part (or all) of the spacecraft for earth return.

The purpose of the spacecraft program is to measure the interplanetary meteoroid environment from the earth out to 2.5 A.U. - either for scientific reasons or as a precursor to manned planetary flights. The spacecraft consists of large folding meteoroid detection panels and the supporting subsystems needed to telemeter the meteoroid impact data to the ground. The program consists of an earth orbital phase and an interplanetary phase. In the earth orbital phase, which is of interest here, the spacecraft is carried into orbit by the Shuttle. The Shuttle crew observes the deployment of the spacecraft panels, notes any difficulties requiring design improvements, and possibly aids in the deployment of panels. After the spacecraft has been in orbit for about a year another Shuttle flight is used to recover the meteoroid detection panels (or possibly the entire spacecraft) so that the telemetered meteoroid impact data can be verified by counting impact craters in the panels. After the earth orbital phase, the spacecraft is launched on its interplanetary trajectory by the Shuttle and a Centaur upper stage. The Centaur has the capability to launch about 9800 lbs out to 2.5 A.U. from 100 nm orbit; this spacecraft weight plus the 34,000 lb Centaur totals 43,800 lbs payload in the Shuttle.

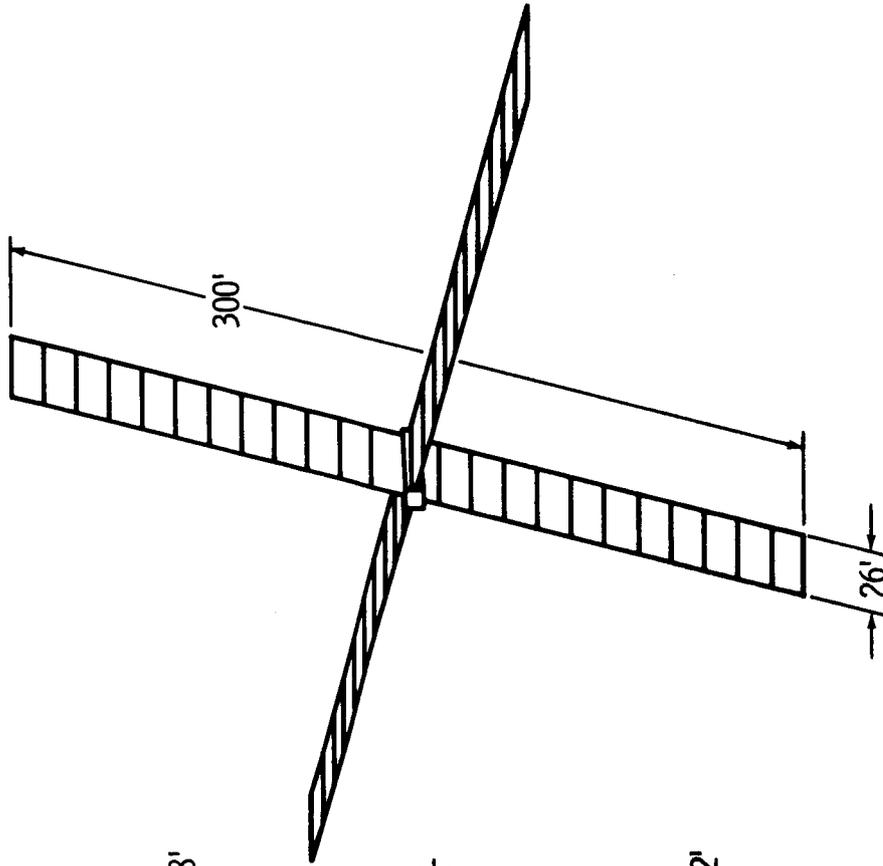
The chart shows the conceptual configuration for the interplanetary meteoroid spacecraft. It is sized to fit in the Shuttle payload bay with a Centaur stage. Assuming 1 inch thick panels with detectors on both sides and a 50% volume efficiency for the folded panel stacks, there is room for about 30,000 square feet of sensor area. In earth orbit this would give about 9000 impacts per year which produce holes equal to or larger than 100 microns - the minimum size for reliable detection in recovered panels.

INTERPLANETARY METEOROID SPACECRAFT

LAUNCH CONFIGURATION:



FLIGHT CONFIGURATION:



PANEL AREA  $\sim 30,000 \text{ FT}^2$   
METEOROID IMPACTS ( $\geq 100 \mu$ )  $\approx 9000$  PER YEAR  
( $\geq \text{IMM}$ )  $\approx 9$  PER YEAR

SHUTTLE EXPERIMENT MODULE

In addition to using the Shuttle for transporting satellites into orbit, the Shuttle provides an opportunity to perform short term (approximately ten days or less) experiments which are returnable. This mode of operation would be similar to that now being carried out by the NASA aircraft research program using the Convair 990. In the aircraft research mode, most of the instrumentation has been ground-based laboratory equipment temporarily mounted inside the aircraft to perform a variety of experiments which required the 40,000 ft altitude.

For the Shuttle, a crew and experiment module carried in the Shuttle bay could provide the environment for performing scientific studies. The experiments mounted inside the module would be designed so that they could be changed from one mission to the next without making any fundamental changes in the module itself. Several gimbaled platforms for astronomy mounted outside the module would provide broad viewing capability.

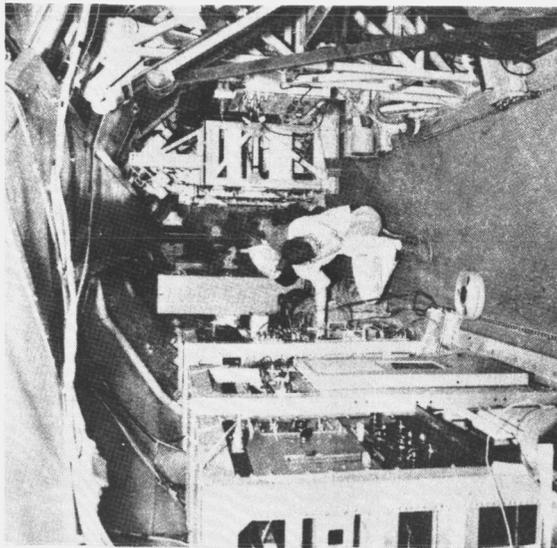
In this section we consider two experiment modules, one which fills the entire Shuttle bay and a smaller version which only fills one third of the bay, leaving room for a large satellite and an upper stage.

CONVAIR 990 PROGRAM 1968 SOLAR CONSTANT EXPEDITION

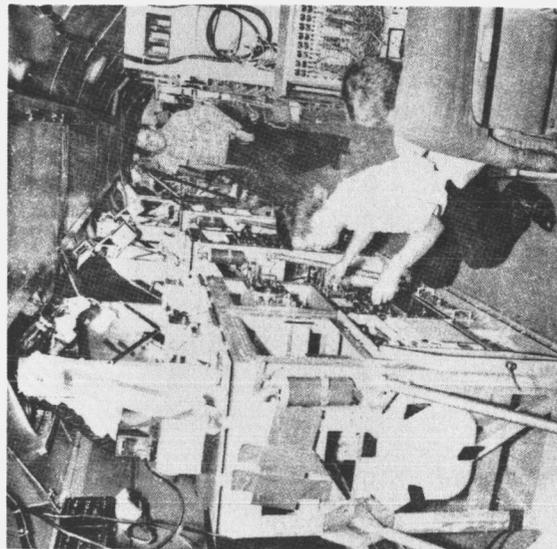
These photographs, reprinted from a NASA report on the Convair 990 Program solar constant expedition carried out in 1968, illustrate the configuration of experiment instrumentation and the overall similarities with a typical ground-based laboratory. Instruments are mounted on standard racks for easy replacement after a mission. Most of the instrumentation on board (in terms of weight and volume) consists of separate units such as amplifiers and data recording systems which have been borrowed from a ground-based laboratory and may be returned after the airborne mission has been completed. Power outlets suitable for standard laboratory equipment are mounted on the aircraft walls. Small optical quality windows have been installed to fit specialized experiment requirements. Provisions for attitude control beyond those supplied by the standard passenger aircraft must be assumed by the individual experiments.

The two bottom photos show the investigators in relative comfort checking over their equipment during flight.

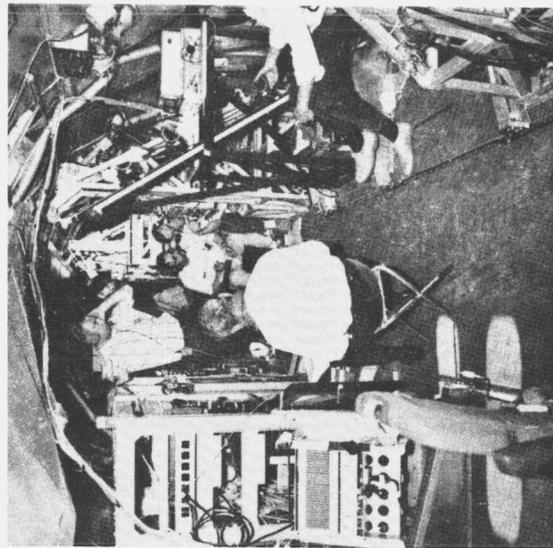
CONVAIR 990 PROGRAM 1968 SOLAR CONSTANT EXPEDITION



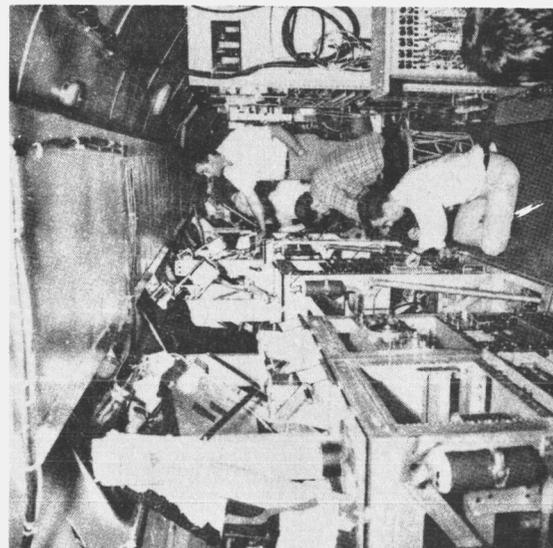
VIEW DOWN THE AISLE TOWARDS  
THE REAR OF THE SPACECRAFT



VIEW UP THE AISLE TOWARDS  
THE FRONT OF THE AIRCRAFT



FRONT SECTION OF THE AIRCRAFT-EXPERIMENTERS  
DURING IN-FLIGHT CALIBRATION OF THE EQUIPMENT



MID SECTION OF THE AIRCRAFT-EXPERIMENTERS  
DURING IN-FLIGHT CALIBRATION OF THE EQUIPMENT

## CONVAIR 990 RESEARCH PROGRAM ADVANTAGES COMPARED TO SATELLITES

This chart illustrates some of the salient features of the CV-990 program. This information was derived from planning documentation prepared by the NASA airborne research program.

This program has been in operation since 1965 and much valuable experience has been gained in the management of what, for NASA, is a rather unique adventure. Two different classes of missions have been flown: expeditions carrying 10-15 experiments, and special purpose missions with 1-10 experiments. Expeditions may last weeks to months, with essentially the same equipment flown once a day for several tens of days (not consecutively). Special purpose missions such as solar eclipse observations may be completed in a matter of minutes.

Payload costs have been relatively low in the CV-990 program, largely because very little new equipment has been developed. As expected, costs rise if development is required. The 36" IR telescope being developed to fly in a new aircraft, the C-141, is an example of an experiment being developed solely for the airborne research program. This telescope will cost several million dollars and weigh around 10 thousand pounds.

The primary factors which stimulate our interest in exploring this type of experiment mode for the Shuttle are that it has been successful from the point of view of producing useful experiment results, and it has been cheap. Since the Shuttle is a kind of space plane and has the stated objective of providing cheap transportation, many of the key advantages of this experiment mode over satellites could well be exploited by the Shuttle program.

CONVAIR 990 RESEARCH PROGRAM  
ADVANTAGES COMPARED TO SATELLITES

- SHORT LEAD TIME FOR EXPERIMENTS  
PREFER 6 MONTHS; 10 DAYS POSSIBLE
- LARGE PAYLOAD CAPABILITY, LABORATORY ENVIRONMENT  
~20,000 LBS., ~15' x 80'  
(10 - 15 EXPERIMENTS PLUS SUPPORT EQUIPMENT AND PERSONNEL)
- RELATIVELY INEXPENSIVE OPERATION

<u>FY - 68 FLIGHT HOURS</u>	<u>FY - 68 COSTS</u>
OSSA - 350	FLIGHT OPERATIONS - 1.4 M
OART - 80	CV-990 MODIFICATIONS - .2
	EXPERIMENTS - .5

- OBSERVATION: FOR SEVERAL DIFFERENT PAYLOADS PER YEAR,  
EXPERIMENT HARDWARE COSTS ~ 20 DOLLARS/LB
- REASON: MOSTLY STANDARD LAB EQUIPMENT, BORROWED OR RENTED  
NEW INSTRUMENT DEVELOPMENT COSTS: 300 DOLLAR\$/LB (36" IR TELESCOPE)
- PERSONNEL ABOARD FOR DECISION, REPAIR, ADJUSTMENT  
LABORATORY ENVIRONMENT FOR SCIENTISTS AND TECHNICIANS
- COMPLETELY RECOVERABLE SYSTEM  
POST-MISSION INSTRUMENT CALIBRATION  
INSTRUMENT REUSE  
DATA RETURN ON FILM OR TAPE
- SAME AIRCRAFT USED FOR MULTIPLE MISSIONS  
AURORA STUDIES IN ARCTIC (NIMBUS)  
SOLAR ASTRONOMY (OSO)  
EARTH RESOURCES (ERTS)

## SHUTTLE EXPERIMENT MODULE CONFIGURATIONS

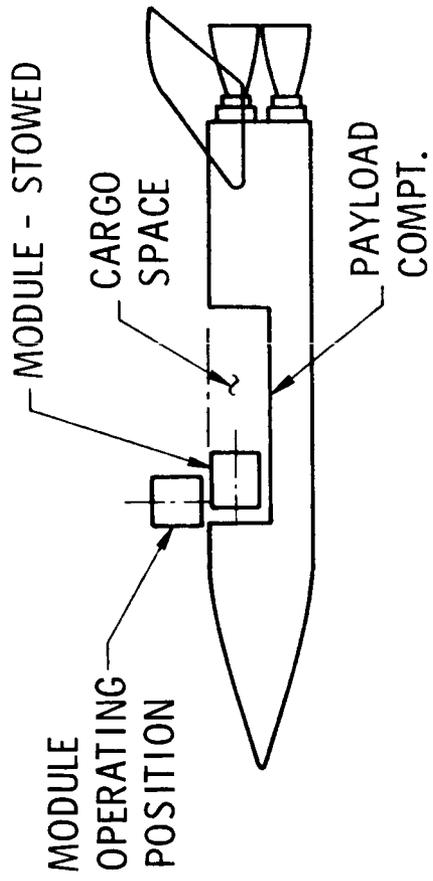
The Convair 990 experiment mode can be extended to space by the use of a completely self-contained module which may be hinged outward from the Shuttle bay to provide accessibility for space viewing. This chart illustrates the large and small modules in their stowed and deployed positions. Experiments mounted inside the module would be similar in concept and sophistication to those performed in the aircraft.

The upper configuration, or small experiment module, was designed for a minimum experiment capability and was limited to using only 20 feet of the Shuttle cargo bay. The remaining cargo space of 40 feet is allotted to other payloads such as the OAO, HEAO, or the Space Tug. On-orbit operating period for this configuration can be as short as 18 hours or up to 10 days, depending on consumables.

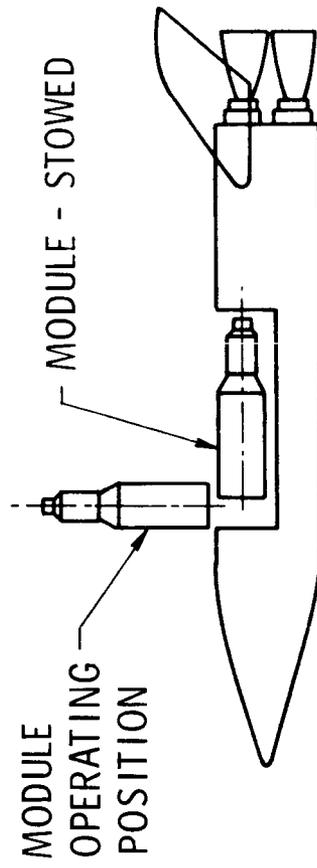
The other configuration, the large experiment module, was configured for a maximum experiment program and makes full use of the Space Shuttle cargo space. The subsystems and consumables in this module are sized for 10 days in orbit.

The operational mode for both configurations uses the Space Shuttle as a support platform only at structural attach points.

SHUTTLE EXPERIMENT MODULE  
CONFIGURATIONS



SMALL EXPERIMENT MODULE



LARGE EXPERIMENT MODULE

## COMPARISON OF SHUTTLE EXPERIMENT MODULE AND CV-990 AIRCRAFT OPERATIONS

This chart compares several aspects of the CV-990 operational mode with projected aspects of the Shuttle Experiment Module mode.

Three different versions of the Shuttle module were explored. The large module is sized to occupy the entire Shuttle bay volume and remain in orbit approximately 10 days. Ten days was selected because it is consistent with the Shuttle work statement (approximately one week in orbit) and because, as will be shown later, there are a number of useful experiments which can be accomplished in this period of time. The crew size is fixed by the volume available in the module. The number of experiments is determined by using the rule of thumb derived from the CV-990 analogy that there are between one and two investigators per experiment. Supporting crew refers to people in the module who are not investigators; the actual flight crew (pilot, navigator, etc.) are additional.

The small module was sized so that it could be flown piggyback on satellite delivery and recovery missions. The short term (18-hour) version was explored as the closest time analog to the aircraft operations (typically 5 hours). The 18-hour duration was selected as representing the longest time the crew could operate without food preparation and sleep facilities. The long term small module (10-day) would have fewer experiments that require continuous operation (such as astronomy and space physics). This is because the 5-man crew limitation and sleep requirement restrict the number of men available to operate these experiments at any given time.

To determine cost/flight for the Shuttle Experiment Modules, it is assumed that the Shuttle costs 3 million dollars per mission and that payload costs are prorated on a volume basis. Since the small module occupies one-third the bay volume, it assumes a per flight cost of one million dollars.

COMPARISON OF SHUTTLE EXPERIMENT MODULE AND  
CV-990 AIRCRAFT OPERATIONS

	<u>OCCUPIED VOLUME (FEET)</u>	<u>FLIGHT DURATION</u>	<u>COST/ FLIGHT</u>	<u>NO. OF EXPERI- MENTS</u>	<u>INVESTI- GATORS/ SUPPORT- ING CREW</u>	<u>TURN AROUND TIME FOR VEHICLE REFLIGHT</u>	<u>PAYLOAD (LBS.)</u>	<u>POWER (KW)</u>
CV-990 AIRCRAFT	10x100	5 HR.	10K	10-12 1-10	UP TO 20/1	1 DAY	10,000 1-5,000	>20
SHUTTLE MODULE								
LARGE (LONG TERM)	15x60	10 DAYS	3M	8	12/2	2 WEEKS	7,000	20
SMALL (SHORT TERM)	15x20	18 HRS.	1M	4	5/0	2 WEEKS	3,200	5
SMALL (LONG TERM)	15x20	10 DAYS	1M	3	4/1	2 WEEKS	3,200	5

#### SHUTTLE EXPERIMENT MODULE PAYLOAD

Typical studies to be performed onboard the Shuttle are listed here. The emphasis is on astronomy, with some time devoted to earth resources and bioscience. In addition, the possibility of instrument development studies done onboard in the space environment is considered.

SHUTTLE EXPERIMENT MODULE PAYLOAD

- ASTRONOMY AND SPACE SCIENCE
  - STUDIES OF SHORT TERM EVENTS ( ~ 10 DAYS OR LESS )
    - SOLAR ACTIVE REGIONS
    - ECLIPSES
    - AURORAL EVENTS
    - NOVAE
    - POLAR PARTICLE EVENTS
  - LONG TERM OR CONTINUOUS STUDIES
    - UV OBSERVATIONS (STELLAR, SOLAR & PLANETARY)
    - X- $\gamma$  RAY OBSERVATIONS (STELLAR & SOLAR)
    - IR OBSERVATIONS (STELLAR, SOLAR & PLANETARY)
- BIOSCIENCE
  - CIRCADIAN RHYTHM EXPERIMENTS WHICH HAVE TERRESTRIAL DECAY TIMES OF 5 DAYS OR LESS
    - NEUROSPORA GROWTH AND SPORULATION
    - HAMSTER BODY TEMPERATURE
  - GROWTH RATE MEASUREMENTS
    - YEAST
    - MICRO-ORGANISMS
    - WHEAT
  - PHYSIOLOGY OF SMALL MAMMALS IN WEIGHTLESSNESS
    - CARDIOVASCULAR REFLEXES
    - FLUID BALANCE
    - NEUROLOGICAL ADAPTATION
    - CIRCADIAN PERIODICITY IN METABOLISM
- EARTH APPLICATIONS
  - DEVELOPMENTAL - GROUND TRUTH DATA ACQUISITION
  - OPERATIONAL - NATIONAL SURVEYS OF SLOWLY VARYING PHENOMENA
- INSTRUMENT DEVELOPMENT
  - SCIENCE AND APPLICATIONS EXPERIMENTS PLANNED FOR LATER OPERATIONAL USE

#### MANNED ACTIVITIES

Man's duties onboard the Shuttle experiment module will be similar to those on the Convair 990. The tasks listed here for astronomy and bioscience are also similar to those performed in ground-based facilities. All data taken will be stored onboard to avoid complications of telemetry.

## MANNED ACTIVITIES

### ASTRONOMY

- TELESCOPE SET-UP
  - DEPLOY TELESCOPES IN AIRLOCK
  - INSTRUMENTATION CHECKOUT
  - MAKE CALIBRATION OBSERVATIONS
- STELLAR OBSERVATIONS
  - ACQUIRE SOURCES
  - ACTIVATE STAR TRACKERS
  - MAKE REAL TIME DECISIONS TO IMPROVE QUALITY OF DATA
- SOLAR OBSERVATIONS
  - VERIFY SOLAR TRACKER OPERATION
  - SEARCH FOR ACTIVE REGIONS OR FLARES
- ON BOARD DATA HANDLING
  - "QUICK LOOK" DATA ANALYSIS ONLY
  - VERIFY PROPER OPERATION OF DATA TAPES
- TELESCOPE MODIFICATIONS IN ORBIT
  - SENSOR REPLACEMENT
  - FILTER AND GRATING REPLACEMENT
  - REPAIR/REPLACE "BREAD BOARD" SENSORS OR OTHER INSTRUMENTATION

### BIOSCIENCE

- SPECIMEN & ANIMAL CARE
  - FEEDING
  - WASTE CONTROL
  - GENERAL HEALTH OBSERVATION
- EXPERIMENT SET-UP AND MAINTENANCE
  - CABIN ATMOSPHERIC TESTS
  - INSTRUMENT OPERATION TESTS AND CALIBRATION
- INITIAL GROWTH PROCESSES
  - EGG FERTILIZATION
  - INCUBATE BACTERIA
- EXPERIMENT OPERATIONAL PROCEDURES
  - DIRECT MEASUREMENTS OF GROWTH
  - MICROSCOPIC STUDIES
  - CENTRIFUGE OPERATION
  - ADMINISTERING STIMULUS FOR EXPERIMENTS
  - CHEMICAL ANALYSIS
- REENTRY PREPARATION

## EXPERIMENT CAPABILITY

Two sets of experiments were assumed for the two different modules, as indicated. Each experiment set is consistent with the crew time and module size of the corresponding supporting module. The sizes for individual instruments do not refer to any particular design which is in existence; they are general dimensions which should be adequate for the experiments shown and they have been used as part of the requirements for the experiment module design study.

## EXPERIMENT CAPABILITY

- SMALL SHUTTLE EXPERIMENT MODULE (SSEM) (18 HRS & 10 DAYS)
  - 2 STELLAR TELESCOPES (1 FT DIA X 3 FT LONG)  
(VACUUM ENVIRONMENT OPERATION - NO SERVICING CAPABILITY)
  - 2 OPTIC EXPERIMENTS (1 FT DIA X 3 FT LONG)  
(INTERNAL TO MODULE WITH EXTERNAL VIEWING PORTS)
  - EXPERIMENT MONITORING EQUIPMENT - CONSOLES, RACKS, ETC.
- LARGE SHUTTLE EXPERIMENT MODULE (LSEM) (10 DAYS)
  - 2 STELLAR TELESCOPES (2 FT DIA X 5 FT LONG)  
(VACUUM ENVIRONMENT OPERATION - PRESSURIZED SERVICING REQUIREMENT)
  - 1 STELLAR TELESCOPE (2 FT DIA X 5 FT LONG)  
(VACUUM ENVIRONMENT OPERATION - NO SERVICING REQUIREMENT)
  - 1 SOLAR TELESCOPE (2 FT DIA X 5 FT LONG)  
(VACUUM ENVIRONMENT OPERATION - NO SERVICING REQUIREMENT)
  - 2 OPTIC EXPERIMENTS (1 FT DIA X 3 FT LONG)  
(INTERNAL TO MODULE WITH EXTERNAL VIEW PORTS)
  - MINIMUM BIOSCIENCE EXPERIMENT STATION
  - MINIMUM EARTH RESOURCES PACKAGE  
(POINTED BY SHUTTLE ORIENTATION)
  - EXPERIMENT MONITORING EQUIPMENT - CONSOLES, RACKS, ETC.

## SMALL SHUTTLE EXPERIMENT MODULE

Configuration - This experiment module has a minimum experiment capability and is limited to partial use of the Space Shuttle cargo space (20 feet). The module is 15 feet in diameter and 15 feet long with the remaining available space used for the module deployment mechanism.

The module interior is oriented about a partition running in the longitudinal direction separating the vehicle into two decks. At the forward end of the module on both sides of the partition are located the crew seats for launch and reentry and a sleep area. Aft of this area on the upper side of this partition are located the internal instruments and experiment monitoring positions. The Environment Control/Life Support (EC/LS) system, water and waste management, along with a crew rest area are located on the opposite side. This floor also functions as a structural support of the flat-faced bulkheads at each end of the module.

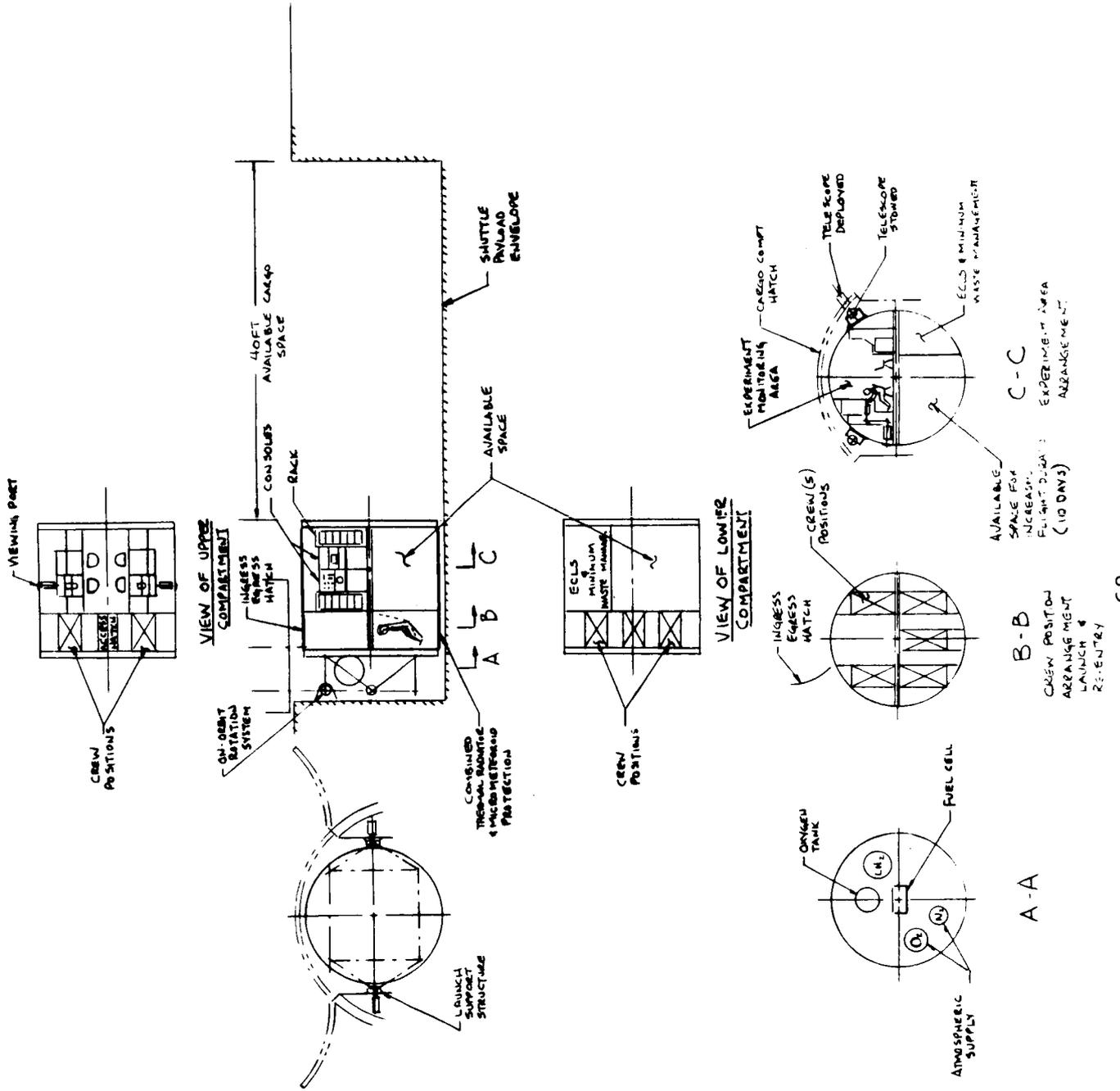
Duration - Mission duration for this module is either 18 hours or 10 days.

Crew - The crew complement is 5 investigators for the 18-hour missions or 4 investigators and one support crew member for the 10-day mission.

Power - The electric power system provides a maximum output of 5 kw. It is an MOL-type fuel cell and is located on the outboard side of the forward bulkhead. This system also fulfills the crew water requirements. The system is the same for both the 18-hour and 10-day missions, with O<sub>2</sub> and H<sub>2</sub> offloaded for the shorter mission.

EC/LS System - The EC/LS system is an open loop system. The one exception to this operation is the H<sub>2</sub>O by-product of the fuel cells which is stored and used as required. Here again the system is designed for the 10-day mission with offloading for the 18-hour mission. To reduce weight for the shorter mission, some systems such as food management and crew sleep accommodations have been removed. Heat is dissipated by radiators on the external surface of the module.

# SMALL SHUTTLE EXPERIMENT MODULE



**A-A**  
 OXYGEN TANK  
 FUEL CELL  
 ATMOSPHERIC SUPPLY

**B-B**  
 CREW POSITION  
 ARRANGEMENT  
 LAUNCH &  
 RE-ENTRY

**C-C**  
 AVAILABLE SPACE FOR  
 INCREASING  
 FLIGHT DURA  
 (10 DAYS)  
 EXPERIMENT AREA  
 ARRANGEMENT

## LARGE SHUTTLE EXPERIMENT MODULE

Configuration - This module, sized for a more extensive experiment program, occupies most of the Space Shuttle payload bay of 60 feet.

The experiment and living unit is configured similar to the small experiment module with a partition through the center of the module separating the unit into two decks. This arrangement provides crew seats for launch and reentry and a sleep area on both decks at the forward end of the unit. Just aft of the upper crew seat area is located the bioscience station. The remaining part of this module is arranged with the internal instruments and experiment monitoring station on the upper compartment and a crew dining and comfort area located in the lower compartment. Support systems such as the EC/LS system and waste management area are also in this area. The floor also provides the same structural support to the flat bulkheads as with the small module. A hatch is provided in the aft bulkhead for access to an airlock supporting astronomy and earth resources experiments.

The airlock mounted to the end of the experiment and living area is sized to support two externally mounted telescopes plus two stellar telescopes which can be serviced inside the airlock but are deployed outside for observations. An earth resources package is mounted at the end of this airlock.

Duration - Mission duration for this experiment module is 10 days.

Crew - For this mission mode there are 14 crew members aboard consisting of 12 scientific investigators and 2 support crew members.

Power - The electric power for this module is provided by four (4) MOL-type fuel cells rated at 5 kw each. This system is located on the external face of the forward bulkhead in the area of the module deployment structure. The H<sub>2</sub>O, a by-product of this system, provides the crew water supply.

EC/LS System - The EC/LS system is an open loop system similar to the small experiment module. Heat is dissipated by radiators on the external surface of the module.



SHUTTLE EXPERIMENT MODULE WEIGHT SUMMARY

This table gives a weight summary for the three alternate mission profiles studied. The small experiment modules with the same experiment programs vary in weight slightly due to expendables offloading.

SHUTTLE EXPERIMENT MODULE WEIGHT SUMMARY

	SSEM (18 HRS)	SSEM (10 DAYS)	LSEM (10 DAYS)
● STRUCTURE	4500	5000	11200
● ELECTRICAL POWER SYSTEM	1100	1800	6400
● EC/LS	860	1400	2000
● CREW SYSTEMS	1800	1900	5200
● EXPERIMENTS	3200	3200	7000
● MISC @ 5%	540	700	1700
	<u>12000 LBS.</u>	<u>14000 LBS</u>	<u>33500 LBS</u>

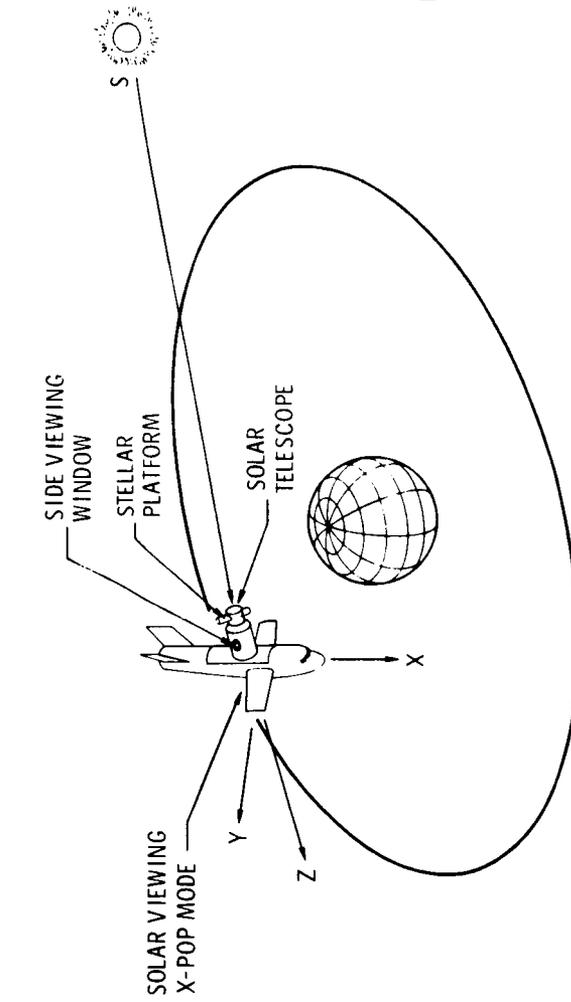
## SPACE SHUTTLE ORBITAL ORIENTATION

Two orientation modes were selected for the Space Shuttle to perform the experiment programs. These modes are oriented to maximize experiment coverage with minimum attitude control requirements on the Space Shuttle. These are:

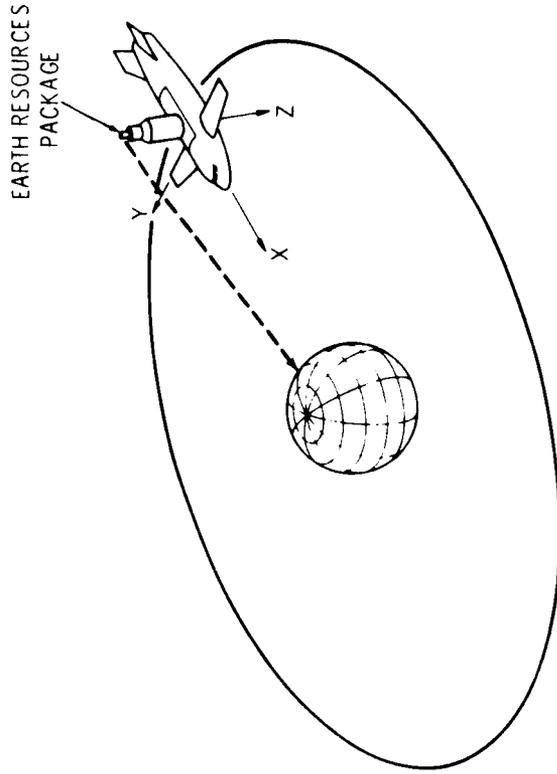
- Inertially oriented mode - This mode of operation places the Shuttle with the long-axis perpendicular to the orbital plane. This orientation permits wide view angles for stellar and solar experiments.
- Earth oriented mode - This mode of operation places the Shuttle with the long-axis in the local vertical direction. Continuous earth viewing is maintained by initially rotating the Shuttle at the rate of one revolution per earth orbit period.

SPACE SHUTTLE ORBITAL ORIENTATION

INERTIALLY ORIENTED MODE  
(SOLAR VIEWING)



EARTH ORIENTED MODE  
(EARTH RESOURCES VIEWING)



## SPACE EXPERIMENT MODES

This chart lists several characteristics of the spectrum of space experiment modes. Costs for satellite and rocket flights are total mission costs, of which the payload is generally a small part. For balloons and aircraft flights where the vehicle can be recovered and reused, costs are for single flight use of the transportation vehicle. For these systems the experiment payload may cost orders of magnitude more than the flight cost and may be reused. Shuttle Experiment Module (SEM) costs are assumed to break down much like the aircraft program, i.e., the cost figure shown is for flight operations, while the reusable payload could cost much more to develop. Flight costs for the SEM assume shuttle trip costs of 3 and 20 million dollars with prorating on a payload volume basis.

The C-141 aircraft mode is an extension of the CV-990 program. Its primary objective will be to fly the 36" IR telescope now under development. This telescope is expected to cost around three million dollars.

SPACE EXPERIMENT MODES

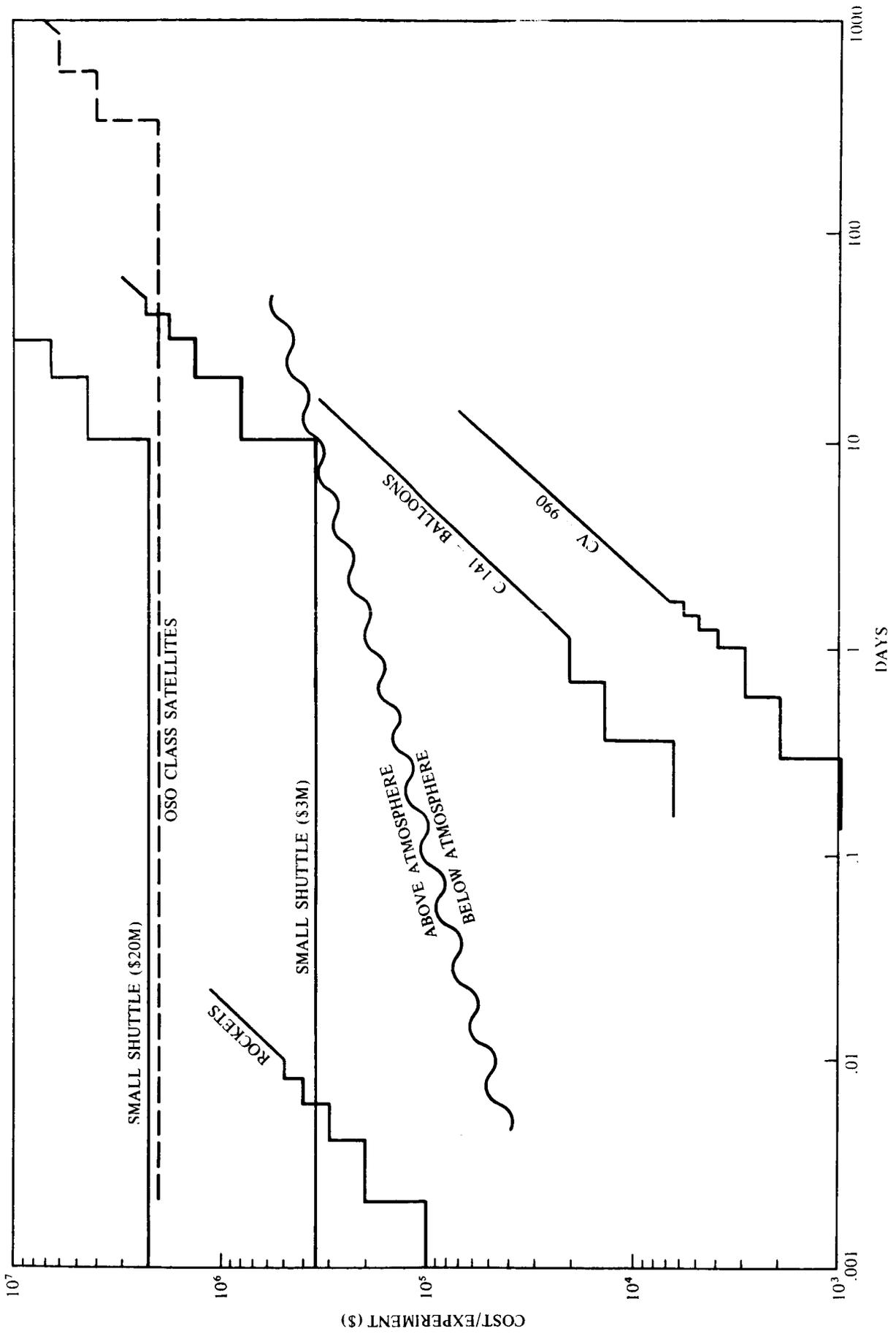
<u>VEHICLE</u>	<u>NO. OF EXPERIMENTS IN TYPICAL FLIGHT</u>	<u>FLIGHT COST</u>	<u>FLIGHT TIME</u>	<u>COST/ EXPERIMENT</u>
UNMANNED SATELLITES				
OAO(A-C)	2	75M	1 YR.	37M
OSO (F-1)	10	20M	1 YR.	2M
ROCKET	1	100K	3 MIN.	100K
BALLOON	1	10K	6 HRS.	10K
CV-990 A/C	10	10K	5 HRS.	1K
C-141 A/C	1	7K	7 HRS.	7K
SHUTTLE MODULES				
10 DAY-LARGE (\$3M)	8*	3M	10 DAYS	375K
10 DAY-SMALL (\$3M)	3*	$\frac{3M^{**}}{3}$	10 DAYS	333K
10 DAY-SMALL (\$20M)	3*	$\frac{20M^{**}}{3}$	10 DAYS	2.2M

\*MAINTAINING 1-2 INVESTIGATORS PER EXPERIMENT

\*\*MODULE USES 1/3 OF SHUTTLE PAYLOAD VOLUME

## SPACE TRANSPORTATION ECONOMICS

On the chart on the opposite page the cost per experiment is plotted as a function of time on a log-log scale. Each "step" represents a reflight of the same experiment on the given transportation system. Because of the nature of the log-log plot the steps rapidly converge to a straight line as the number of reflights becomes large. Satellite lifetime was taken as one year, which is twice the design plan for current OSO experiments. Note that when experiments need to be above the atmosphere for a period of time between about 10 minutes and 40 days, the \$3M Shuttle is the most economical transportation system. We have shown only the small module (20 ft) on this chart at two Shuttle trip cost levels, 3 and 20 million dollars. The previous chart indicated there is little difference between the small and large modules on a cost/experiment basis. The 18-hour version of the small module, not shown on this chart, would be cost effective between about 10 minutes and 3 days. It is interesting that at the 10-day period the Shuttle module (flown on the 3 million dollar per mission Shuttle) becomes competitive with the C-141 aircraft configured to carry one experiment. The OSO satellite competes favorably with the \$20M Shuttle for experiments requiring less than 10 days. The OAO at ~\$37M per experiment is considerably more expensive than all other experiment systems considered.



SPACE TRANSPORTATION ECONOMICS

## SHUTTLE/SATELLITE TRAFFIC MODEL

The purpose of this section is to determine the launch rate and cost savings afforded by the Shuttle and associated equipment in support of unmanned satellite programs as a function of the Shuttle operating cost. A reference model of the satellite programs from 1970 to 1981 was surveyed to determine the satellite programs to which the Shuttle might be applicable. Criteria for applicability were based largely on assumed cost savings. An estimate of potential savings resulting from Shuttle use was made for this unmodified model. Then the model was modified to reflect the impact of the Shuttle on these programs. Finally a traffic model giving launch rates for the years 1977 through 1979 was constructed based on the modified satellite program model, and average cost savings for these years were computed.

### APPLICABILITY OF SHUTTLE TO THE EXISTING UNMANNED PROGRAM

The Baseline II mission model developed by Battelle Memorial Institute for NASA was used as the reference mission model. (1) This model is a modification of the automated portion of Option III of the NASA report to the Space Task Group. The modifications reflect data from the NASA FY 1971 submissions to the Bureau of the Budget. The model covers the period of time 1970-1981 and includes 328 earth orbital and planetary missions using conventional rocket boosters. The total value of the spacecraft is about 9.5 billion dollars and their total weight is about 490,000 pounds. Non-NASA missions such as communications satellites are also included. Cost estimates were derived principally from the NASA Planning Steering Group reports.

The applicability of both the 50K and 25K Shuttles was considered. These nominal payloads are to a 270 nm, 55° inclination orbit, with a greater or lesser payload to other orbits. Shuttle operating cost levels of 3, 20, and 75 million dollars were used. These costs approximately cover the range between reusable and interim, partly reusable Shuttle concepts. The 50,000 lb gross weight Space Tug was assumed to cost 3 million dollars per use.

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(1) Enclosure, Letter from D. A. Nippert to J. E. McGolrick, Battelle Memorial Institute, File ref. BMI-NLVP-IL-69-315, December 12, 1969.

All of the 328 missions in the Battelle mission model were grouped into flight programs such as OAO and OSO. These programs were placed in applicable or not applicable categories depending primarily on whether the Shuttle could be used to reduce program costs. Such cost reductions might come from reduced launch costs, reduced spacecraft costs, or both. Working assumptions were that to qualify for Shuttle launch, the Shuttle flight should cost less than the competitive rocket booster. If the rocket booster and the Shuttle cost nearly the same (within \$1M) the rocket booster was used rather than to risk the Shuttle crew, except when the spacecraft would be configured for recovery by the Shuttle. If a spacecraft qualified for recovery, the Shuttle was used for launch if it cost within \$1M of the rocket booster to avoid building a spacecraft compatible with both a rocket and the Shuttle. To qualify for Shuttle recovery, the spacecraft should cost more than twice the recovery cost, be physically possible to recover, and be reasonably desirable to recover. The twice recovery cost requirement is based on the assumption that the value of a spacecraft with any recovery value at all is equal to half its initial cost. Some spacecraft were considered to have no recovery value for reasons peculiar to the program, such as a short useful spacecraft lifetime. Each mission was assumed to be operated independently; multiple launches or other combined missions were not considered. Recovery costs included the operating costs of the Shuttle(s) and Tug(s) needed to recover the spacecraft.

Programs in the non-applicable category all had rocket boosters nearly equal in cost or less expensive than the Shuttle and were not suitable for recovery either because the spacecraft was too inexpensive, was impossible to recover, or was not desirable to recover for a variety of reasons. The chart tabulates the numbers, cost, and weight of spacecraft not applicable to the Shuttle having a 3 million dollar per mission cost. Average spacecraft weight and cost and typical missions are shown for each of the three sub-categories in the not applicable category. As the cost of the Shuttle increases, more programs fall into this category. The possibility of combining two or more non-applicable missions into one which would be applicable was not considered.

NOT APPLICABLE FOR INDIVIDUAL SHUTTLE OPERATIONS

EXAMPLE	NUMBER	COST (\$M)	WEIGHT (LBS)	AVERAGE COST (\$M)	AVERAGE WEIGHT (LBS)
INEXPENSIVE BOOSTER AND PAYLOAD TOO INEXPENSIVE FOR RECOVERY.	161	1105	90,200	6.9	560
INEXPENSIVE BOOSTER AND PAYLOAD NOT POSSIBLE TO RECOVER.	29	1176	20,900	40.6	720
INEXPENSIVE BOOSTER AND PAYLOAD NOT DESIRABLE TO RECOVER.	68	976	45,500	14.4	670
TOTALS	258	3257	156,600		

UNMODIFIED MISSION MODEL - SATELLITES APPLICABLE WITH THE \$3M AND \$20M SHUTTLE

Programs were placed in the applicable category if the Shuttle could be used to reduce program costs. These programs had a booster more expensive than the Shuttle or were suitable for Shuttle recovery or both. The chart shows the missions applicable to the \$3M Shuttle. Missions in the Launch Only sub-category are typically planetary missions and have boosters costing more than \$3M, e.g., Titan. Missions in the Recovery Only sub-category are typically synchronous and low earth orbit applications satellites with spacecraft costs around \$25M and booster requirements less than or equal to the \$3M Atlas. Some missions meet both the launch and recovery criteria and form a third sub-category. These are the facility-class science missions, such as HEAO and OAO, at about \$70M, synchronous orbit applications at \$50-100M, and sun-synchronous applications missions at about \$35M. All of these have boosters costing more than \$3M.

As the cost of the Shuttle increases to \$20M, only the programs indicated by an asterisk meet the cost criteria. For example, the Broadcast Satellite which costs about \$50M and is launched by a \$20M booster and a \$10M upper stage would require two Shuttle flights and two Tug flights to recover it from geostationary orbit. The cost of this operation is \$12M at the \$3M Shuttle cost level. Since the recovered Broadcast satellite is assumed to be worth half its original cost, or \$25M, it qualifies for recovery. The Shuttle is less expensive than the booster; therefore, this program also qualifies for launch with the Shuttle. At the \$20M Shuttle cost level the satellite recovery costs are \$46M (\$20M + \$20M + \$3M); hence, the program does not qualify for recovery. Although the rocket booster and the Shuttle now cost the same, the rocket booster is favored on the basis of crew safety, and this program does not qualify for Shuttle launch either.

At the \$75M cost level, none of the missions qualify for use with the Shuttle according to the cost criteria.

UNMODIFIED MISSION MODEL - SATELLITES  
 APPLICABLE WITH THE \$3M AND \$20M SHUTTLE

LAUNCH ONLY		RECOVER ONLY		LAUNCH AND RECOVER	
<u>NO.</u>	<u>MISSION</u>	<u>NO.</u>	<u>MISSION</u>	<u>NO.</u>	<u>MISSION</u>
2	OUT OF ECLIPTIC PIONEERS	1	SATS DATA COLLECTION	7*	OAO, LST, & TELESCOPE
5	VIKINGS	2	ATS H&J		TECHNOLOGY
1	HIGH DATA-RATE ORBITER	2	NAVIGATION & T/C	4*	HEAO
1	JUPITER PIONEER FLYBY	8	ESSA LOW ORBIT	2*	DRSS
1	JUPITER ENTRY PROBE	1	ORBITAL SCANNER	1	BROADCAST SATELLITES
2	JSP SWINGBY PROBES	1	LASER COMMUNICATIONS	2	ATS F&G
2	JUN SWINGBY PROBES	3	CENTAUR INTERNATIONAL	6	ERTS
1	COMET D'ARREST FLYBY	3	CENTAUR DOD	6	NIMBUS
1	GENERAL RELATIVITY PROBE				
5	INTELSAT V				
<u>21</u>	<u>MISSIONS</u>	<u>21</u>	<u>MISSIONS</u>	<u>28</u>	<u>MISSIONS</u>

\*THESE MISSIONS ALSO APPLICABLE AT \$20M COST LEVEL

## COST SAVINGS (1970-1981)

The approximate total program cost saving in each of the three sub-categories of applicable programs is shown in the chart for three different Shuttle operating cost levels. Cost savings in the Launch Only sub-category were calculated as the total of the differences between the rocket booster cost and the Shuttle costs. The cost savings in the Recovery Only sub-category were the total of all spacecraft recovery values minus recovery operations costs. For the Launch and Recovery sub-category, launch cost savings on boosters and spacecraft savings were calculated in the same way as in the other sub-categories and are shown separately.

With the \$3M Shuttle, Titan-class boosters are eliminated saving an average of about \$50M a year. About \$60M per year is saved by recovering spacecraft assuming the spacecraft are worth half their original cost (including certain large "once only" satellites such as the Telescope Technology Satellite). Most of the savings are in the facility-class astronomy and high energy physics and communications satellites, all of which are long term programs. At the \$75M Shuttle cost level there is no traffic, hence no savings.

Major cost savings result from replacing Titan boosters and reusing the facility-class satellites. The cost saving in replacing Titans is relatively certain, but the cost saving from reusing facility-class satellites (assumed to be half the satellite cost) is still a major question.

COST SAVINGS (1970 - 1981)  
(IN MILLIONS OF DOLLARS)

SHUTTLE COST LEVEL SUB-CATEGORY	3	20	75
LAUNCH ONLY	BOOSTERS ~ 340	0	0
RECOVERY ONLY	SPACECRAFT ~ 120	0	0
LAUNCH AND RECOVERY	BOOSTERS ~ \$250 SPACECRAFT ~ \$635	BOOSTERS ~ \$30 SPACECRAFT ~ 170 (OAO, LST, TELES. TECH. HEAO, DRSS)	0
TOTALS	1345	200	0

#### MODIFIED UNMANNED PROGRAMS

The number of missions applicable to the Shuttle and the cost savings were based on all the missions in the 12-year Battelle mission model. The Shuttle will not be available all of this time; hence, a specific time period (1977 through 1979) was considered to determine more realistically the traffic and cost savings associated with the Shuttle. The same applicability criteria based mostly on costs was used to determine when and how the Shuttle would be used. Those programs applicable for launch only were considered to be launched as scheduled with a Shuttle instead of a conventional rocket booster. Programs involving recovery were modified to reflect the impact of the Shuttle. The spacecraft and the entire program were modified extensively for the OAO and HEAO, as previously described. The flight schedule and orbits of these programs were adjusted so that some combined missions supporting both these programs could be flown. For other programs the flight schedule was changed from occasional launches of new spacecraft to maintain a working satellite in orbit to regular recovery and relaunch. The chart shows the on-orbit times for the modified satellite programs. Shuttle Experiment Modules were carried on the Shuttle whenever weight and space permitted.

MODIFIED UNMANNED PROGRAMS

	1977	1978	1979
0AO TELESCOPE	██████████	██████████	██████████
INTERFEROMETER	██████████	██████████	██████████
SERVICE FLIGHT		██████████	██████████
HEAO SATELLITE		██████████	██████████
SERVICE FLIGHT		██████████	
DRSS SATELLITE		██████████	██████████
ATS SATELLITE	██████████	██████████	██████████
SATS DATA COLLECTION*	██████████	██████████	██████████
NAVIGATION & T/C*	██████████	██████████	██████████
ORBITAL SCANNER*	██████████	██████████	██████████
BROADCAST SATELLITE	██████████	██████████	██████████
NIMBUS	██████████	██████████	██████████
CENTAUR CLASS SATELLITES*	██████████	██████████	██████████
LASER COMMUNICATIONS*	██████████	██████████	██████████

\* SHUTTLE RECOVERY, ROCKET LAUNCH

## TRAFFIC MODEL

The following three charts show the traffic model assuming that satellites will be recovered, serviced on the ground, and relaunched. It is also assumed that at least two Shuttles and two Tugs are available (e.g., for satellite missions requiring two Tugs in a staged mode). The payload weight and approximate capacity of the Shuttle to the required orbit are shown in thousands of pounds. The number shown without parentheses in the payload "weight" column is the total weight of a basic payload defined as those items without parentheses in the "payload up" column. (Some missions have no basic payload.) This basic payload can be carried by either the 25K or 50K Shuttle. On some missions an additional payload element is launched depending on which Shuttle is available. This is added either to use up more payload capability, as in the case of the Shuttle Experiment Module, or to provide extra propulsion to reach the Nimbus orbit, as in the case of the Tug. This additional payload element is enclosed in single parentheses if it is included when the 50K Shuttle is used; it is enclosed in double parentheses if it is flown only on the 25K Shuttle. The weight shown in parentheses is the total of the basic payload and the additional payload element.

The number of Shuttle flights is independent of the type of Shuttle, although the number of Tugs and Shuttle Experiment Modules is not. The 25K Shuttle requires the help of a Tug in the Nimbus program because it cannot reach the sun-synchronous Nimbus orbit. It delivers a Tug into a coplanar 100 nm orbit from which the Tug can deliver or recover the Nimbus satellite in its 600 nm orbit. The 25K Shuttle carries fewer piggyback Shuttle Experiment Modules, but it is capable of supporting all of the satellite programs in the modified mission model.

The number of Shuttle flights is a function of the Shuttle cost since the number of applicable programs depends on Shuttle cost. Since none of the programs meet the cost criteria at the \$75M Shuttle operating cost level, no traffic is shown at this cost level. Use of the Shuttle at the \$75M cost level may be desirable on a basis other than reduced costs. For example, the increased effectiveness of the Large Space Telescope missions may be sufficient to justify the use of the \$75M Shuttle.

TRAFFIC MODEL  
1977

NUMBER OF FLIGHTS		PAYLOAD UP ( ) = 50K ONLY, (( )) = 25K ONLY	WEIGHT (K POUNDS)	CAPACITY		PAYLOAD DOWN
\$3M	\$20M			50K	25K	
1	0	VIKING, CENTAUR	44	75	50	—
2	0	JSP, CENTAUR	36	75	50	—
1	1	OAO TELESCOPE	30	55	30	—
1	1	OAO INTERFEROMETER	30	55	30	—
1	0	BROADCAST SAT., TUG, (SSEM)	50, (64)	75	50	TUG, (SSEM)
1	0	TUG, (SSEM)	50, (64)	75	50	TUG, (SSEM)
1	0	—, ((TUG))	—, ((20))	10	20*	NIMBUS, ((TUG))
1	0	NIMBUS, ((TUG))	1.5, ((18.5))	10	20*	((TUG))
1	0	TUG, (SSEM)	50, (64)	75	50	TUG, LASER COMM. SAT, (SSEM)
1	0	TUG, (SSEM)	50, (64)	75	50	TUG, (SSEM)
2	0	SSEM	14	55	30	CENTAUR CLASS SAT, SSEM
—	—					
13	2					

\*100 NM, 100° ORBIT

SSEM = SMALL SHUTTLE EXPERIMENT MODULE  
LSEM = LARGE SHUTTLE EXPERIMENT MODULE

TRAFFIC MODEL  
1978

NUMBER OF FLIGHTS		PAYLOAD UP ( ) = 50K ONLY, (( )) = 25K ONLY	WEIGHT (K POUNDS)	CAPACITY		PAYLOAD DOWN
\$3M	\$20M			\$75M	50K	
1	0	JUPITER PROBE, CENTAUR	38	75	50	—
1	1	HEAO	30	55	30	OAO TELESCOPE
1	1	OAO TELESCOPE	30	55	30	—
1	1	((LSEM)), ((SSEM)) SERVICE FLT.	((34)), ((14))	55	30	((LSEM)), ((SSEM))
2	2	DRSS, TUG, (SSEM)	50, (64)	75	50	TUG, (SSEM)
2	2	TUG, (SSEM)	50, (64)	75	50	TUG, (SSEM)
1	0	TUG, (SSEM)	50, (64)	75	50	ATS, TUG, (SSEM)
2	0	TUG, (SSEM)	50, (64)	75	50	TUG, (SSEM)
1	0	ATS, TUG, (SSEM)	50, (64)	75	50	TUG, (SSEM)
1	0	SSEM	14	45	20	SATS, SSEM
1	0	TUG, (SSEM)	50, (64)	75	50	NAV. & T/C SAT., TUG, (SSEM)
1	0	SSEM	14	40	15	ORBITAL SCANNER, SSEM
—	—					
15	7					

TRAFFIC MODEL  
1979

NUMBER OF FLIGHTS			PAYLOAD UP ( ) = 50K ONLY, (( )) = 25K ONLY	WEIGHT CAPACITY (K POUNDS)		PAYLOAD DOWN
\$3M	\$20M	\$75M		50K	25K	
2	0	0	JUN, CENTAUR	50	50	—
1	1	0	—	—	30	OAO TELESCOPE
1	1	0	OAO TELESCOPE	30	30	HEAD
1	1	0	((LSEM), ((SSEM))) SERVICE FLT.	(34), ((14))	30	((LSEM), ((SSEM)))
1	0	0	TUG, (SSEM)	50, (64)	50	BROADCAST SAT., TUG, (SSEM)
2	0	0	TUG, (SSEM)	50, (64)	50	TUG, (SSEM)
1	0	0	BROADCAST SAT., TUG, (SSEM)	50, (64)	50	TUG, (SSEM)
1	0	0	—, ((TUG))	—, ((20))	20*	NIMBUS, ((TUG))
1	0	0	NIMBUS, ((TUG))	1.5, ((18.5))	20*	—, ((TUG))
2	0	0	SSEM	14	30	CENTAUR CLASS SAT., SSEM
1	0	0	TUG, (SSEM)	50, (64)	50	LASER COMM. SAT, TUG, (SSEM)
1	0	0	TUG, (SSEM)	50, (64)	50	TUG, (SSEM)
—	—	—				
15	3	0				

\*100 NM, 100° ORBIT

## TRAFFIC MODEL SUMMARY AND COST SAVINGS

This chart summarizes the traffic model by giving the total number of flights per year for the Shuttle and each piece of associated equipment in the years 1977-1979. The number of Shuttle flights decreases sharply with increasing Shuttle cost and is independent of the type of Shuttle (50K or 25K). The number of Tug flights is significant only at the \$3M Shuttle cost level; it is increased slightly by using the 25K Shuttle. The number of large Shuttle Experiment Module flights piggybacking on the unmanned satellite program averages less than one per year with the 50K Shuttle and is zero with the 25K Shuttle. At the \$3M cost level, an average of 8 small Shuttle Experiment Modules per year are carried with the 50K Shuttle and only 3 per year with the 25K Shuttle.

This traffic model includes only flights supporting missions for which the Shuttle was judged applicable on an individual mission basis. Some small missions might be combined to utilize additional Shuttle flights. Shuttle flights in support of new unmanned programs, such as the meteoroid detection spacecraft, might also be added, as well as additional independent flights of the manned Shuttle Experiment Module.

The average yearly cost savings at the three Shuttle cost levels is also shown. These cost savings were generally computed as before for the unmodified program, i.e., launch cost savings were the difference between the rocket booster costs and the Shuttle cost, and spacecraft savings were one-half the spacecraft cost minus the recovery cost. A somewhat more complex algorithm was used for the OAO/HEAO program; the spacecraft were assumed to cost \$100M except for a \$50M interferometer, the service flight costs equal the Shuttle operating costs, and spacecraft refurbishments cost \$20M plus the recovery and relaunch costs.

TRAFFIC MODEL SUMMARY

DEPENDING ON SHUTTLE OPERATING COST: \$3M, \$20M, \$75M

SHUTTLE TYPE	1977		1978		1979	
	50K	25K	50K	25K	50K	25K
SHUTTLE FLIGHTS	13, 2, 0	13, 2, 0	15, 7, 0	15, 7, 0	15, 3, 0	15, 3, 0
TUG FLIGHTS	4, 0, 0	6, 0, 0	9, 4, 0	9, 4, 0	6, 0, 0	8, 0, 0
LSEM FLIGHTS*	0, 0, 0	0, 0, 0	1, 1, 0	0, 0, 0	1, 1, 0	0, 0, 0
SSEM FLIGHTS*	6, 0, 0	2, 0, 0	11, 4, 0	3, 1, 0	8, 0, 0	3, 1, 0

\*CARRIED PIGGYBACK WHENEVER POSSIBLE

AVERAGE ANNUAL COST SAVINGS  
(IN MILLIONS OF DOLLARS)

SHUTTLE COST LEVEL	3	20	75
ANNUAL SAVINGS	140	10	0

## TUG/TELEOPERATOR ORBITAL REPAIR

To further reduce program costs, the satellite programs might use a remotely controlled teleoperator to service satellites in orbit rather than recover them to the ground for service and relaunch. If the teleoperator flight costs nearly the same as the recovery flight, using a teleoperator makes it possible to save the relaunch costs. The potential amount of these savings and the effect of using a teleoperator on the traffic model were investigated by assuming that a teleoperator would perform all satellite servicing for all programs except for the OAO and HEAO programs which were specifically designed for ground servicing.

The teleoperator was assumed to weigh 1000 lbs and require a Space Tug to transfer it from the Shuttle orbit, maneuver it to the satellite, and return it to the Shuttle. The Space Tug could boost the teleoperator from 100 nm orbit to any orbit required except geostationary (0° geosynchronous) and return it to 100 nm orbit. Two Tugs operating in a staged mode would be needed to service satellites in geostationary orbit. The teleoperator was assumed capable of performing all desired repairs or upgrading on orbit with a negligible weight allowance for parts. The teleoperator was also assumed not to increase significantly the size (15 ft diameter, 24 ft long) of the Space Tug. The cost of operating the teleoperator was assumed to be equal to the \$3M cost of operating the Tug alone.

The chart shows the traffic model summary using the Tug/teleoperator mode. An average of 4 Tug/teleoperator flights per year are made with a slight increase in the number of Tug flights and a slight reduction in the number of Shuttle and small Shuttle Experiment Module flights. The additional cost savings beyond that afforded by satellite recovery and relaunch are also shown. These savings are the total of the differences between the combined recovery and relaunch costs and the Tug/teleoperator flight cost.

Obviously the results of these traffic model and cost analyses are sensitive to the assumptions. To minimize the complexity of the results, only one cost and one operational mode for teleoperator repair have been assumed. Other possibilities include throwaway teleoperators on a conventional booster, like Agena. It is felt that the establishment of one reference mode for Tug operations will serve as a useful basis for comparison with other assumed costs and operational modes.

TRAFFIC MODEL SUMMARY  
 WITH TUG/TELEOPERATOR  
 DEPENDING ON SHUTTLE OPERATING COST: \$3M, \$20M, \$75M

YEAR	1977		1978		1979	
	50K	25K	50K	25K	50K	25K
SHUTTLE FLIGHTS	11, 2, 0	11, 2, 0	13, 7, 0	13, 7, 0	11, 3, 0	11, 3, 0
TUG FLIGHTS	6, 0, 0	6, 0, 0	9, 4, 0	9, 4, 0	6, 0, 0	6, 0, 0
TUG/TELEOPERATOR FLIGHTS	4, 0, 0	4, 0, 0	4, 0, 0	4, 0, 0	5, 0, 0	5, 0, 0
LSEM FLIGHTS*	0, 0, 0	0, 0, 0	1, 1, 0	0, 0, 0	1, 1, 0	0, 0, 0
SSEM FLIGHTS*	6, 0, 0	2, 0, 0	9, 4, 0	1, 1, 0	6, 0, 0	1, 1, 0

\* CARRIED PIGGYBACK WHENEVER POSSIBLE

AVERAGE ADDITIONAL ANNUAL COST SAVINGS  
 AFFORDED BY TUG/TELEOPERATOR  
 (IN MILLIONS OF DOLLARS)

SHUTTLE COST LEVEL	3	20	75
ANNUAL SAVINGS	33	0	0

## RESULTS AND CONCLUSIONS

The Shuttle could be used to replace the booster stage for launching earth orbital and planetary satellite missions. From a payload weight and volume standpoint, all satellites in the 12-year mission model could be delivered with an upper stage no larger than Centaur. Low altitude earth orbital satellites such as OAO and HEAO could be delivered and recovered directly (i.e., no upper stage required). Geosynchronous satellites could be recovered by the Space Tug, although two stages might be required (depending on Tug performance and satellite weight).

The potential effect of the availability of the Space Shuttle on satellite design and the resulting programmatic implications are complex. In an attempt to explore these matters, large, facility-class satellites (OAO and HEAO) were examined in some detail. The effect of the launch weight and volume capability of the Shuttle was evident in relaxing some constraints, but it did not lead to any fundamentally different payload design. This aspect needs to be investigated further with smaller satellites which, with the Shuttle as the delivery vehicle, might grow 1-2 orders of magnitude in weight and volume.

The opportunity for satellite revisit or recovery offers greater challenges in restructuring future programs (although revisit is not unique to the Shuttle). Revisit for repair and payload updating appears to be an attractive mode if satellites are made up of modular, replaceable units. Earlier studies had indicated that on-orbit repair at the component level would be impractical. Both OAO and HEAO could benefit from Shuttle recovery and relaunch. Key elements of the payload could be repaired or replaced during ground servicing without major configuration changes. With proper initial payload design, a single satellite could operate over a period of many years and accomplish the same scientific objectives as a multi-satellite program which does not have recovery.

Two new classes of experiment payloads are made possible with the Shuttle. One is a satellite system requiring earth return which, because of some special feature such as size, sensitivity to reentry environment, etc., has not been considered in the present planning. The second, the Shuttle Experiment Module (SEM), provides the opportunity for carrying out manned experiments and space observations in a capsule carried in the Shuttle bay. The experiment program for this module is patterned after the NASA airborne research

program. Concepts for two different sized modules were investigated. A module occupying the entire Shuttle bay was found to be capable of supporting 14 men for 10 days at a gross payload weight of 34K pounds. A module occupying one-third of the bay (15' x 20') could support 5 men for 10 days at a gross weight of 14K pounds.

As a mode for carrying out experiments in earth orbit, the SEM offers cost advantages when compared with present rocket and satellite mission costs. If the Shuttle can be operated at 3 million dollars per mission, the SEM mode is the most economical for experiments requiring operational periods between about 10 minutes and 40-100 days (i.e., 4-10 Shuttle flights). The 40-day figure is based on a comparison with OSO, which is a relatively efficient satellite on a cost per experiment basis; 100 days is based on a comparison with OAO. A 20 million dollar per mission Shuttle offers cost advantages compared with OAO, but not when compared with OSO.

A traffic model was developed outlining the satellite payload market for Shuttles costing 3, 20, and 75 million dollars per round trip. The lowest cost is construed to represent an efficient, fully reusable Shuttle while the two higher costs refer to interim, partially reusable vehicles. On the assumption that the Shuttle, carrying only one satellite per round trip, is used for satellite launch when it costs less than the required expendable booster, and for satellite recovery when the total recovery cost is less than half the initial satellite cost, the following picture of the traffic model emerges. With a 3 million dollar per mission Shuttle, approximately 1/5 of the satellite traffic for the years 1970-1981 shows a cost savings if a satellite is either launched, recovered, or launched and recovered by the Shuttle. Average annual cost savings are 50 million dollars/year for booster elimination (primarily Titan) and 60 million dollars/year in recovered spacecraft (primarily from a few expensive spacecraft: OAO, HEAO, and DRSS). With the 20 million dollar Shuttle, Titan savings are eliminated and only a few expensive spacecraft are worth recovering. Average annual savings decrease to about 16 million dollars/year. There are no Shuttle flights and no consequent savings with the 75 million dollar Shuttle.

To establish a more detailed view of the traffic, a model was set up for the years 1977-79 showing each Shuttle flight and its up and down payload. The average annual cost savings over the three year period for the 3, 20, and 75 million dollar Shuttles were 140, 10, and 0 million dollars, respectively. The average number of Shuttle flights per year was 14, 4, and 0, respectively. Introducing a Tug-delivered teleoperator for orbital repair

of satellites in lieu of the Shuttle recovery and relaunch mode provided additional savings in the 3 million dollar Shuttle program of 33 million dollars per year (with no effect on the 20 and 75 million dollar Shuttle programs). The number of Shuttle flights per year was independent of whether the payload capability was 25K or 50K pounds. The small Shuttle Experiment Module, designed to be flown in a piggyback mode in conjunction with a satellite launch and/or recovery mission, can be carried more often with the larger payload capability Shuttle. For the 3 million dollar per mission Shuttle, there was an average of 8 opportunities per year for SEM flight with a Shuttle payload of 50K pounds compared to 3 per year with a payload of 25K pounds.

## ISSUES

The ground rules used in this study to screen out the Shuttle satellite traffic leave us with a number of questions, two of which we would like to address here. The first is whether there is any role at all for an interim Shuttle operating at a cost of 75 million dollars per mission. The answer we would like to suggest is that there may well be a viable program of launch and recovery of advanced OAO (referred to in the satellite mission model as LST, Large Space Telescope) and HEAO satellites operating in orbits accessible on a single Shuttle flight. The reasoning is as follows. In determining Shuttle applicability, the traffic model was based on several assumptions: (1) satellite cost is 100 million dollars; (2) the science program for the Shuttle-delivered satellite is essentially the same as the one for the rocket-delivered satellite; (3) sustaining the non-Shuttle program over a period of years with appropriate payload changes can realistically be accomplished by launching a series of satellites on 2-3 year intervals; and (4) the science program bears the full burden of the Shuttle flight cost.

Testing each of these assumptions for OAO and HEAO suggests arguments that make the Shuttle mode appear more attractive. On the question of satellite cost, the design proposed for the Shuttle mode may well involve a 200-300 million dollar investment. This may be justifiable if the Shuttle mode guarantees productivity over an indefinitely long period. On the question of science program content, the discussions of OAO and HEAO in the text have outlined a number of potential improvements in payload performance which may accrue from the large payload capability of the Shuttle and from the possibility of manned attendance. The third assumption bears on the question of the proper way to operate a scientific facility, which is the way OAO and HEAO should be viewed. The mode that scientists are familiar with through ground-based research programs is clearly the one provided by the Shuttle: a single facility is developed with the capability for improvements and continued research over a period of many years. Finally, on the question of Shuttle flight cost, it is likely that a large part of the cost of any interim Shuttle would be appropriately charged to the flight capability development effort of OMSF.

The second question concerns the algorithm used to determine cost savings for recovered satellites. For the traffic model calculations it was assumed that cost savings were equal to half the original satellite cost minus the Shuttle recovery cost. Recovered satellites were responsible for approximately half the total savings with the three million dollar Shuttle and assumed a greater proportion of the savings with the more expensive

Shuttles. Further understanding of the potential cost savings for representative satellite programs is required. The model for estimating these savings should be a detailed satellite design and program plan structured for Shuttle operations.

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